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ASSESSMENT METHODS OF PARTNERING RELATIONS OF POLISH, SLOVAK AND UKRAINIAN CONSTRUCTION ENTERPRISES WITH THE USE OF FUZZY LOGIC

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The paper shows methods of analysis and assessment of partnering relations of construction enterprises with the use of questionnaires, statistics, and fuzzy logic. The results were obtained from Polish, Slovak and Ukrainian enterprises. The definition of partnering in the construction industry indicates that it is a qualitative concept. By applying a scale in the questionnaire, and due to mathematical analysis of the data, the final research result, showing the level of partnering relations of construction enterprises, is rendered quantitatively.

Key words: partnering relations, partnering, construction enterprise, fuzzy logic.

1. Introduction

In 1991, the Construction Industry Institute proposed the following definition: partnering is "a long-term commitment between two or more organizations for the purposes of achieving specific business objectives by maximizing the effectiveness of each participant's resources. This requires changing traditional relationships to a shared culture without regard to organizational boundaries. The relationship is based on trust, dedication to common goals, and an understanding of each other's individual expectations and values. Expected benefits include improved efficiency and cost effectiveness, increased opportunity for innovation, and the continuous improvement of quality products and services" [10, p. IV]. In the same year 1991, The Associated General Contractors of America defined partnering co-operation as "a way of achieving an optimum relationship between a customer and a supplier. It is a method of doing business in which a person's word is his or her bond and where people accept responsibility for their actions. Partnering is not a business contract but a recognition that every contract includes an implied covenant of good faith" [1, p. 2]. An important study, which describes the 7 pillars of partnering in the construction industry, is a book by Bennett, Jayes [5].

There are only a few Polish publications on the subject, including mainly the ones by the (present) Author [21, 22, 23, 24, 25, 26, 27, 28, 29, 30]. Many more works have

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been published abroad. The phenomenon is developing in some countries more than in the others. Most papers appear in the USA, Britain, Australia, Hong Kong. The authors of many of them have aimed at analysis of the very process of partnering, including the distinction of its characteristics based on examination of particular construction enterprises. These are e.g. Yeung, Chan, Chan, Li [34], Young, Chan, Chan [33], Eriksson, Pesämaa [12]. A system of partnering co-operation assessment was proposed by e.g. Cheung, Suen, Cheung [9], Bayliss, Cheung, Suen, Wong [3], Nyström [18], Cheng, Li [8]. Beach, Webster and Campbell [4] assess the progress of the British construction industry in the implementation of the partnering approach; they predict that the trend towards the application of the partnering approach in the construction industry is going to last. Another publication analysing partnering co-operation in the British construction industry is (one) by Black, Akintoye, Fitzgerald [6]. Among works which apply game theory and the "prisoner's dilemma" to their analysis of partnering relations are Sacks and Harel [28], Wong, Cheung, Ho [32]. Another approach is the application of social network analysis by Pryke [20]. Information exchange in a partnering construction enterprise is dealt with by such works as Drejer, Vinding [11], Chan, Cooper, Tzortzopoulos [7], Lipshitz, Popper, Friedman [16]. Partnering co-operation in the construction industry on the Far East markets is described e.g. by Phua, Rowlinson [19], Kwan, Ofori [15]. Partnering in Turkey is analysed by Koraltan, Dikbas [14]. Ng, Rose, Mak, Chen [17], as well as Glagola and Sheedy [13] who examine the development of partnering in construction projects commissioned by the government of Australia. All of the publications mentioned here predict the development of partnering and of partnering relations in the construction industry in the future.

2. The author's own research

The concept of partnering relations is not described numerically. It is commonly used in an intuitive way. The 3 basic characteristics of partnering relations, emphasized in all works on the subject, are: long-term relations, partners' common goals, and mutual trust. The author asked the question about criteria which show whether given relations of a partnering enterprise are partnering or traditional. She elaborated a set of 14 parameters qualifying the relations of construction enterprises as either traditional or partnering; she also determined qualitatively the values of these parameters in both cases [23, 25, 29]. The author assumed that the relations may range, on a 5-point scale, from 1: traditional relations to 5: partnering ones. The description of the extremes on this scale is to be found in the above-mentioned publication. In 2008, the author examined the partnering co-operation of construction enterprises with their four basic transactors on the institutional market.

The research method chosen by the author was a standardized interview based on a questionnaire. The methods of questionnaire research and the possibilities of their application in the construction industry were described in the author's textbook [28]. The arrangement and course of the research was as follows. Three countries were selected: Poland, Slovakia and Ukraine. Next, a region was selected in each of them. Due to organizational and financial possibilities, the regions selected were: the małopolskie province in Poland, Košice and Prešov regions in Slovakia and the Transcarpathian Region in Ukraine. The research range, i.e. the area selected for the research in each country, was comparable, amounting to about 13-15 thousand km^2. However, the number of registered construction enterprises in these regions was different, with their largest number in the małopolskie province. While in the case of Poland and Slovakia an attempt might be made to prove that research conducted there was representative of the whole given country (as these regions are typical, average, neither extremely rich nor poor, not including the country's capital), in the case of Ukraine such a statement cannot be made. The Transcarpathian Region is definitely poorer in every respect, also as regards construction enterprises, and it is special in the aspect of its geographic location (bordering with three countries). The selection of the population for the research was as follows. It was assumed that the present research would concern mainly large and medium enterprises. The research was designed as comprehensive, i.e. performed on the whole population rather than on its randomly selected sample. A commonly accepted classification was adopted, according to which microenterprises had up to 9 employees, small construction enterprises had between 10 and 49 employees, medium ones had from 50 to 249 employees and large ones had over 249 employees. The present research disregarded the microenterprises in all 3 countries. Their numbers were therefore not included in Table 1. Since in the selected regions of Slovakia and Ukraine there were over twice fewer medium and large construction enterprises than in the małopolskie province, the research included the largest of the enterprises in the group of the small ones in these two countries. Among the respondents there were specially selected experts from the construction enterprises, who were able to answer the research questions; these were enterprise owners and managers, as well as construction site managers.

The data in Table 1 concerning the number of Polish and Slovak construction enterprises were obtained from statistical offices in these countries whereas the data concerning the number of construction enterprises in Ukraine are approximate as there are no respective publications. The only information the author obtained from the Ukrainian statistical office was the total number of 1036 construction enterprises in the Transcarpathian Region.

For the sake of clarity, whenever the results of the research done in the above-mentioned regions referred to, the author refered to the enterprises in those regions simply as Polish, Slovak or Ukrainian ones.

Table 1

Statistical data concerning the present research. The Author's own elaboration based on data obtained from statistical offices in the analysed regions and from information given by construction experts.
Dane statystyczne odnośnie przeprowadzonych badań Opracowanie własne na podstawie danych uzyskanych z urzędów statystycznych w badanych regionach oraz informacji od ekspertów z branży budowlanej

Country and region name	Area km^2	Number of inhabitants	Number of construction enterprises			
			Small	Medium	Large	Examined
Poland	Małopolskie province (Kraków + area)					
	15 200	**3 282 000**	**888**	**148**	**19**	**147**
Slovakia	Košice region in Slovakia (Koszyce + area)					
	6 753	770 000	282	37	3	81
	Prešov region in Slovakia (Presow + area)					
	8 998	803 000	328	38	0	87
	altogether (Košice and Prešov regions)					
	14 751	**1 573 000**	**610**	**75**	**3**	**168**
Ukraine	Transcarpathian Region (Uzhorod + area)					
	12 777	**1 258 264**	**350**	**35**	**2**	**112**

3. Research results

3.1. Assessment of relation parameter by means of statistical methods

The adopted method of assessment of partnering relations of construction enterprises is presented in Figure 1. Further analysis was performed using the symbols of relation parameters and transactors as in Table 2.

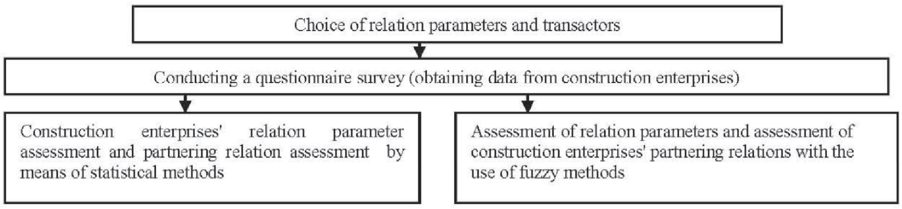

Fig. 1. Methods of assessment of construction enterprises' partnering relations.
Rys. 1. Metodyka oceny relacji partnerskich przedsiębiorstw budowlanych

The collected data underwent statistical analysis. For the assessments, obtained with the interview method, of each relation parameter with four selected transactors, the following values were determined: mean values $\bar{x}$, standard deviations s_x and variability

Table 2

Symbols of relation parameters and transactors.
Oznaczenia parametrów relacji oraz podmiotów

NO.	SYMBOL OF RELATION PARAMETER	NAME OF RELATION PARAMETER
1	A	Basis of order placement
2	B	Number of suppliers
3	C	Approach to service quality control
4	D	Cost division
5	E	Adaptation to market changes
6	F	Participation in the enterprise's new offer
7	G	Mutual relations
8	H	Means of communication
9	I	Information sharing
10	J	Conflict resolution
11	K	Standards and rules of behaviour
12	L	Contact frequency
13	M	Approach to quality issues
14	N	Trust
SYMBOL OF TRANSACTOR		NAME OF TRANSACTOR
1		Material supplier
2		Equipment supplier
3		Subcontractor/main contractor
4		Investor/investor's representative

coefficients c_x on the basis of the following formulas:

(3.1) $$\bar{x}_j^{(k)} = \frac{1}{n} \cdot \sum_{i=1}^{n} x_{i,j}^{(k)}$$

(3.2) $$s_{x_j}^{(k)} = \sqrt{\frac{1}{n-1} \cdot \sum_{i=1}^{n} \left(x_{i,j}^{(k)} - \bar{x}_j^{(k)} \right)^2}$$

(3.3) $$c_{x_j}^{(k)} = \frac{s_{x_j}^{(k)}}{\bar{x}_j^{(k)}}$$

where:

$x_{i,j}^{(k)} \in \{1, 2, 3, 4, 5\}$ – the reply of the expert from the *i- th* construction enterprise to the question about the assessment of the *j-th* parameter of the relation with the *k-th* transactor; assessment on a 5-point scale, *j*= 1,2,...,14, *k*= 1,2,3,4.

n – the number of analysed construction enterprises in particular countries (e.g. for Poland n= 147),

$\bar{x}_j^{(k)}$ – the mean of the experts' replies to the question about the assessment of the *j-th* parameter of the relation with the *k-th* transactor,

$s_{x_j}^{(k)}$ – the standard deviation of the experts' replies to the question about the assessment of the *j-th* parameter of the relation with the *k-th* transactor,

$c_{x_j}^{(k)}$ – the coefficient of variability of the experts' replies to the question about the assessment of the *j-th* parameter of the relation with the *k-th* transactor.

Analogous formulas were used in the analysis of the assessment of parameter importance. Assessment of data distribution relative to the mean value was performed with the use of the variability coefficient c_x, which allowed for assessing the degree of data distribution better than the standard deviation s_x, as it was determined relative to the mean value, and is the equivalent of the relative error. Low values of the variability coefficient on the level of 0.05 indicate that the mean value reflects the analysed data correctly.

The assessment of the partnering relations of construction enterprises with particular transactors may be determined as the weighted mean of the average assessments of particular parameters. This method is justified in the case when the variability coefficients for particular average assessments of parameters are low. Analysis of the variability coefficients for particular countries (Table 3) showed that most of them assume high values amounting to 0.3 or even 0.5. What follows is that the mean values of parameter assessments do not reflect the analysed data well enough. Therefore, the final assessment of the relation with a given transactor may contain a large error. With regard to the above analysis, it was decided to apply fuzzy logic in the assessment of the relation parameters.

3.2. ASSESSMENT OF RELATION PARAMETERS WITH THE USE OF FUZZY LOGIC

Fuzzy set A determined in the universe of discourse X is defined as a set of pairs $A = \{(\mu_A(x), x)\}$ where the function $\mu_A : X \to [0, 1]$ is a membership function of fuzzy set A, whereas $\mu_A(x)$ is the degree of the membership of element x to set A. The membership of an element $x \in X$ in the fuzzy set A in the zero degree $\mu_A(x) = 0$ is an equivalent of the classical case of not belonging to a set. Partial membership of an element $x \in X$ in a fuzzy set A: $0 < \mu_A(x) < 1$ means that an element x belongs to a fuzzy set A to a certain degree. The full membership of an element $x \in X$ in a fuzzy set A: $\mu_A(x) = 1$ corresponds to classical membership in a set. In fuzzy set theory, the passage from membership to non-membership is gradual rather than punctuated. Fuzzy sets can be used to model situations of a lack of precision and partial information, situations naturally regarded as qualitative, with descriptive parameters, not precisely determined but having approximate meaning. Fuzzy sets allow for formal expression

Table 3

Mean values $\bar{x}$, standard deviation s_x, variability coefficient c_x for relation parameter assessments obtained from experts in Polish, Slovak and Ukrainian construction enterprises.

Wartości średnie $\bar{x}$, odchylenie standardowe s_x, współczynnik zmienności c_x dla ocen parametrów relacji uzyskanych od ekspertów w polskich, słowackich i ukraińskich przedsiębiorstwach budowlanych

Parameter	Question about parameter importance			Question about assessment of relation with transactor 1			Question about assessment of relation with transactor 2			Question about assessment of relation with transactor 3			Question about assessment of relation with transactor 4		
	Polish construction enterprises														
	$\bar{x}$	s_x	c_x	$\bar{x}$	s_x	c_x	$\bar{x}$	s_x	c_x	$\bar{x}$	s_x	c_x	$\bar{x}$	s_x	c_x
A	3.67	1.09	0.30	3.37	1.11	0.33	2.98	1.16	0.39	3.51	1.10	0.31	3.53	1.18	0.33
B	3.54	1.24	0.35	3.37	1.26	0.37	3.17	1.34	0.42	3.60	1.21	0.34	3.32	1.15	0.35
C	3.88	1.13	0.29	3.37	1.30	0.38	3.15	1.38	0.44	3.08	1.28	0.42	3.07	1.23	0.40
D	3.62	1.04	0.29	3.38	1.25	0.37	3.16	1.24	0.39	3.37	1.16	0.34	3.56	1.14	0.32
E	3.57	1.19	0.33	3.09	1.26	0.40	2.80	1.33	0.47	3.29	1.20	0.36	3.33	1.16	0.35
F	3.37	1.04	0.31	3.41	1.21	0.35	2.87	1.24	0.43	3.49	1.20	0.34	3.31	1.23	0.37
G	3.68	1.13	0.31	3.06	1.38	0.45	2.65	1.30	0.49	3.05	1.29	0.42	2.84	1.37	0.48
H	3.82	1.01	0.26	3.48	1.13	0.32	3.12	1.24	0.40	3.86	0.96	0.25	3.67	1.14	0.31
I	3.63	1.07	0.29	3.41	1.13	0.33	3.09	1.20	0.39	3.54	1.06	0.30	3.47	1.09	0.31
J	3.98	0.98	0.25	3.55	1.21	0.34	3.31	1.24	0.37	3.40	1.05	0.27	3.82	1.16	0.30
K	3.76	0.87	0.23	3.44	1.13	0.33	3.20	1.14	0.35	3.72	0.97	0.26	3.48	1.17	0.34
L	3.77	1.04	0.28	3.67	1.21	0.33	3.09	1.28	0.41	3.87	0.98	0.25	3.55	1.21	0.34
M	4.27	0.88	0.20	3.66	1.19	0.32	3.51	1.19	0.34	3.96	1.07	0.27	3.86	1.13	0.29
N	3.95	0.98	0.25	3.59	1.10	0.31	3.45	1.08	0.31	3.75	1.04	0.28	3.42	1.12	0.33

Table 3 [cd]

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Parameter	Slovak construction enterprises														
	$\bar{x}$	s_x	c_x	$\bar{x}$	s_x	c_x	$\bar{x}$	s_x	c_x	$\bar{x}$	s_x	c_x	$\bar{x}$	s_x	c_x
A	3.67	0.99	0.27	2.96	1.25	0.42	2.95	1.09	0.37	3.03	1.07	0.35	3.07	1.19	0.39
B	3.58	1.00	0.28	3.66	0.95	0.26	3.56	0.95	0.27	3.66	1.01	0.28	3.46	1.10	0.32
C	3.77	1.06	0.28	3.75	1.05	0.28	3.50	1.10	0.31	3.44	1.16	0.34	3.50	1.12	0.32
D	3.84	0.98	0.25	3.74	1.04	0.28	3.69	0.98	0.27	3.73	1.05	0.28	3.73	0.98	0.26
E	3.71	1.15	0.31	3.49	1.19	0.34	3.37	1.10	0.33	3.45	1.08	0.31	3.47	1.23	0.35
F	3.59	0.99	0.27	3.67	1.19	0.32	3.50	1.14	0.33	3.74	1.10	0.29	3.70	1.16	0.31
G	3.28	1.07	0.32	2.91	1.25	0.43	2.96	1.13	0.38	3.20	1.14	0.36	3.26	1.16	0.35
H	3.78	1.07	0.28	3.46	1.33	0.38	3.22	1.30	0.40	3.37	1.29	0.38	3.57	1.10	0.31
I	3.35	1.27	0.38	3.29	1.23	0.37	3.13	1.23	0.39	3.53	1.18	0.33	3.65	1.08	0.29
J	3.87	1.03	0.27	3.81	1.10	0.29	3.47	1.14	0.33	3.80	1.09	0.29	3.85	1.04	0.27
K	3.70	0.95	0.26	3.76	1.10	0.29	3.41	1.10	0.32	3.47	1.06	0.30	3.49	1.12	0.32
L	3.59	1.09	0.30	3.63	1.13	0.31	3.53	1.01	0.29	3.63	1,09	0.30	3.45	1.04	0.30
M	3.83	1.03	0.27	3.80	1.02	0.27	3.36	1.03	0.31	3.67	1.08	0.29	3.43	1.04	0.30
N	3.82	1.04	0.27	3.24	1.21	0.37	3.19	1.25	0.39	3.32	1.25	0.38	3.52	1.15	0.33

Table 3 [cd]

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Parameter	Ukrainian construction enterprises														
	$\bar{x}$	s_x	c_x	$\bar{x}$	s_x	c_x	$\bar{x}$	s_x	c_x	$\bar{x}$	s_x	c_x	$\bar{x}$	s_x	c_x
A	3.43	0.99	0.29	2.69	1.04	0.39	2.67	1.09	0.41	2.65	0.97	0.36	2.71	1.29	0.47
B	3.54	0.97	0.27	3.00	1.24	0.41	3.06	1.25	0.41	3.37	1.01	0.30	3.20	1.19	0.37
C	3.51	1.09	0.31	2.59	1.15	0.44	2.47	1.08	0.43	2.59	1.10	0.42	2.84	1.26	0.44
D	3.54	0.97	0.27	3.12	1.32	0.42	3.02	1.16	0.38	3.14	1.22	0.39	3.10	1.18	0.38
E	3.72	0.93	0.25	2.73	1.32	0.48	2.63	1.30	0.49	3.06	1.05	0.34	3.16	1.10	0.35
F	2.90	1.11	0.38	2.69	1.32	0.49	2.28	1.14	0.50	2.59	0.93	0.36	3.16	1.01	0.32
G	3.23	0.94	0.29	2.71	1.29	0.47	2.59	1.21	0.46	2.77	1.10	0.40	2.71	1.21	0.44
H	3.18	0.94	0.29	2.73	1.07	0.39	2.63	0.93	0.35	2.96	0.96	0.32	3.24	0.97	0.30
I	3.05	0.90	0.29	2.82	1.11	0.39	2.51	0.91	0.36	2.77	0.98	0.35	3.08	0.10	0.32
J	3.23	0.84	0.26	3.06	1.16	0.38	2.92	1.08	0.37	3.33	0.99	0.30	3.39	0.97	0.29
K	3.18	0.97	0.31	3.08	1.10	0.35	3.12	0.97	0.31	3.30	1.02	0.31	3.10	1.12	0.36
L	3.21	0.95	0.29	3.08	1.02	0.33	2.71	0.87	0.32	3.12	0.97	0.31	2.92	1.10	0.37
M	3.64	1.09	0.30	3.02	1.25	0.41	3.08	1.13	0.37	3.06	0.97	0.31	3.39	1.09	0.32
N	3.11	0.80	0.26	2.90	0.80	0.27	2.98	0.75	0.25	3.37	0.70	0.21	3.08	0.10	0.32

of imprecise concepts. In the case of such concepts as full partnering relations, partial partnering relations (to a certain degree), a lack of partnering relations (traditional relations), the application of fuzzy set theory seems to be justified.

Preliminary data analysis was conducted for membership functions implemented in the MatLab package. The following types of membership functions were used in preliminary analysis: *trimf, trapmf, sigmf, dsigmf, psigmf, gaussmf, gauss2mf, gbellmf, smf, zmf, pimf.* Detailed analysis was conducted for selected types of membership functions, which best reflected the expert assessment distributions. The selected types of membership functions are: *trimf, gaussmf, gauss2mf.* Figure 2 presents the method of selection of the membership functions.

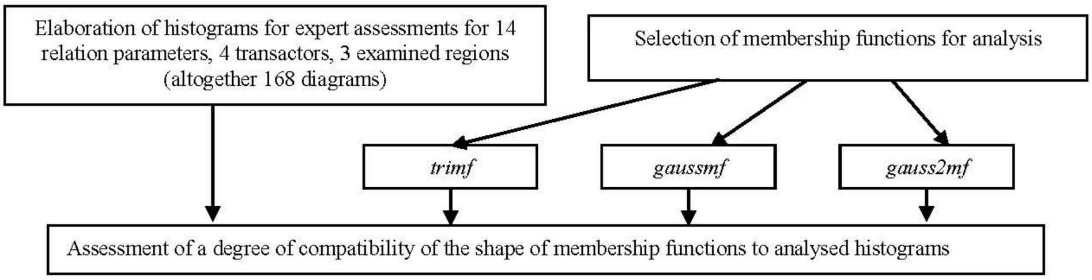

Fig. 2. Method of selection of membership functions.
Rys. 2. Metodyka doboru funkcji przynależności

Parameters of the *trimf* function were determined for the *k-th* transactor and the *j-th* parameter on the basis of assessments made by experts in construction enterprises according to the following formulas:

$$a_j^{(k)} = \min_i \left\{ x_{i,j}^{(k)} \right\} \tag{3.4}$$

$$b_j^{(k)} = \bar{x}_j^{(k)} = \frac{1}{n} \cdot \sum_{i=1}^{n} x_{i,j}^{(k)} \tag{3.5}$$

$$c_j^{(k)} = \max_i \left\{ x_{i,j}^{(k)} \right\} \tag{3.6}$$

where:

$x_{i,j}^{(k)}$ – assessment by the i-th expert, j-th parameter, k-th transactor

n – the number of construction enterprises in a given country.

Parameters of the membership function *trimf* are determined as the minimum expert assessment, the mean of expert assessments, and the maximum expert assessment. This way to determine the parameters of the triangle membership function was proposed by Baas and Kwakernaak [2] in the method of optimum variant selection. The disadvantage of such a choice of a membership function and its parameters is a large influence on the results of extreme assessments. This influence is particularly evident in the case of a large number of experts, which is the case of the present study. The application of the *gauss* membership function reduces this defect. The parameters of the *gauss* function were determined for the *k-th* transactor and the *j-th* parameter on the basis of assessments according to the following formulas:

$$c_j^{(k)} = \bar{x}_j^{(k)} = \frac{1}{n} \cdot \sum_{i=1}^{n} x_{i,j}^{(k)} \tag{3.7}$$

$$\sigma_j^{(k)} = s_{x_j}^{(k)} = \sqrt{\frac{1}{n-1} \cdot \sum_{i=1}^{n} \left(x_{i,j}^{(k)} - \bar{x}_j^{(k)}\right)^2} \tag{3.8}$$

For the membership function *gaussmf* it was assumed that its parameters would be, respectively, the mean of the expert assessments and the standard deviation of these assessments. The advantage of the application of the membership function *gaussmf* with a described way of parameter selection is a reduction of the influence of the extreme assessments in comparison with the previous method, described above. The function of the *gaussmf* type allows for symmetrical distribution. In the present study, the distributions of the expert assessments are in many cases asymmetrical. For this reason, the application of the membership function *gaussmf* makes it possible to note significant differences between a selected membership function and a determined distribution of the expert assessments. The membership function allowing for the modeling of asymmetrical distributions is the the *gauss2mf* function. The parameters of the *gauss2mf* function were determined for the *k-th* transactor and *j-th* parameter on the basis of assessments according to the following formulas:

$$c_{j,2}^{(k)} = c_{j,1}^{(k)} = \bar{x}_j^{(k)} = \frac{1}{n} \cdot \sum_{i=1}^{n} x_{i,j}^{(k)} \tag{3.9}$$

$$\sigma_{j,1}^{(k)} = \sqrt{\frac{1}{n_1 - 1} \cdot \sum_{i \in S_1}^{n} \left(x_{i,j}^{(k)} - \frac{1}{n_1} \sum_{i \in S_1} \bar{x}_j^{(k)}\right)^2} \tag{3.10}$$

$$\sigma_{j,2}^{(k)} = \sqrt{\frac{1}{n_2 - 1} \cdot \sum_{i \in S_2}^{n} \left(x_{i,j}^{(k)} - \frac{1}{n_2} \sum_{i \in S_2} \bar{x}_j^{(k)}\right)^2} \tag{3.11}$$

(3.12) $$S_1 = \left\{ i \in \{1.\dots, n_1\} : x_{i,j}^{(k)} < \bar{x}_j^{(k)} \right\}$$

(3.13) $$S_2 = \left\{ i \in \{1.\dots, n_2\} : x_{i,j}^{(k)} > \bar{x}_j^{(k)} \right\}$$

where:

n_1 – the number of elements of the set S_1,

n_2 – the number of elements of the set S_2.

The *gauss2mf* function is a combination of two functions based on the Gauss distribution so that the character of the left part of the curve is described by the Gauss distribution with the parameters σ_1, c_1 while the character of the right part of the curve is described by the Gauss distribution with the parameters σ_2, c_2. In the method proposed here it was assumed that the parameters c_1, c_2 equal the mean of the expert assessments ($c_1 = c_2$). The σ_1 parameter is determined as the standard deviation of the expert assessments lower than the average assessment, while the σ_2 parameter is determined as the standard deviation of the expert assessments higher than the average one.

The author elaborated all diagrams of functions for particular assessments and weights of the parameters of relations of construction enterprises with four transactors on the market in the selected regions of the three countries. Due to the large number of the diagrams, they are not included in this paper except Figure 3. The parameters

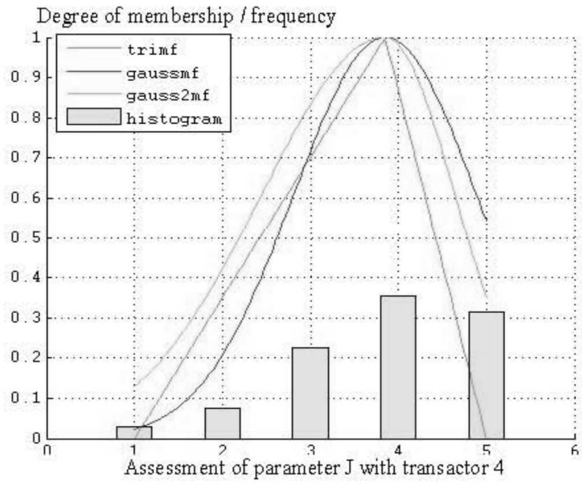

Fig. 3. Shapes of selected membership functions for sample assessments of relation parameters for Slovak construction enterprises.

Rys. 3. Kształty wybranych funkcji przynależności dla przykładowych ocen parametrów relacji słowackich przedsiębiorstw budowlanych

Table 4

Parameters of the selected membership functions for the assessments of the 14 parameters of relations of Polish (P), Slovak (S) and Ukrainian (U) construction enterprises with each of the 4 transactors.

Parametry wybranych funkcji przynależności dla ocen poszczególnych 14 parametrów relacji polskich (P), słowackich (S) i ukraińskich (U) przedsiębiorstw budowlanych z poszczególnymi 4 podmiotami

	Parameters	a_{min}			a_{sr}			a_{max}			a_{σ}			a_{γ}		
		P	S	U	P	S	U	P	S	U	P	S	U	P	S	U
Material supplier	A	1.00	1.00	1.00	3.67	3.67	3.43	5.00	5.00	5.00	1.09	0.99	0.99	0.93	0.88	0.89
	B	1.00	1.00	1.00	3.55	3.58	3.54	5.00	5.00	5.00	1.24	1.00	0.98	1.09	0.85	0.76
	C	1.00	1.00	1.00	3.88	3.77	3.51	5.00	5.00	5.00	1.13	1.06	1.09	0.81	0.85	1.00
	D	1.00	1.00	1.00	3.62	3.84	3.54	5.00	5.00	5.00	1.04	0.98	0.98	0.92	0.78	0.86
	E	1.00	1.00	1.00	3.57	3.71	3.72	5.00	5.00	5.00	1.19	1.15	0.93	1.07	0.89	0.79
	F	1.00	1.00	1.00	3.37	3.59	2.90	5.00	5.00	5.00	1.04	0.99	1.11	1.01	0.84	0.96
	G	1.00	1.00	1.00	3.68	3.29	3.23	5.00	5.00	5.00	1.13	1.07	0.94	0.86	1.00	1.02
	H	1.00	1.00	1.00	3.82	3.78	3.18	5.00	5.00	5.00	1.01	1.07	0.94	0.77	0.76	0.94
	I	1.00	1.00	1.00	3.63	3.35	3.05	5.00	5.00	5.00	1.07	1.27	0.90	0.95	1.23	1.12
	J	1.00	1.00	1.00	3.98	3.87	3.23	5.00	5.00	5.00	0.99	1.03	0.84	0.69	0.77	1.12
	K	1.00	1.00	1.00	3.76	3.70	3.18	5.00	5.00	5.00	0.87	0.95	0.97	0.67	0.77	1.06
	L	1.00	1.00	1.00	3.77	3.59	3.21	5.00	5.00	5.00	1.04	1.09	0.95	0.83	0.93	1.11
	M	1.00	1.00	1.00	4.27	3.83	3.64	5.00	5.00	5.00	0.88	1.03	1.10	0.73	0.87	0.93
	N	1.00	1.00	1.00	3.95	3.82	3.11	5.00	5.00	5.00	0.98	1.04	0.80	0.70	0.81	0.97

Table 4 [cd]

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Equipment supplier	A	1.00	1.00	1.00	3.38	2.97	2.69	5.00	5.00	5.00	1.11	1.25	1.04	1.16	1.06	0.90
	B	1.00	1.00	1.00	3.38	3.66	3.00	5.00	5.00	5.00	1.27	0.95	1.24	1.15	0.85	1.34
	C	1.00	1.00	1.00	3.37	3.75	2.59	5.00	5.00	5.00	1.30	1.05	1.15	1.18	0.90	1.14
	D	1.00	1.00	1.00	3.38	3.74	3.12	5.00	5.00	5.00	1.25	1.04	1.32	1.18	0.81	1.27
	E	1.00	1.00	1.00	3.09	3.49	2.73	5.00	5.00	5.00	1.26	1.19	1.32	1.30	1.06	1.23
	F	1.00	1.00	1.00	3.41	3.67	2.69	5.00	5.00	5.00	1.21	1.19	1.33	1.02	0.87	1.18
	G	1.00	1.00	1.00	3.06	2.91	2.71	5.00	5.00	5.00	1.39	1.25	1.29	1.47	1.10	1.20
	H	1.00	1.00	1.00	3.48	3.46	2.73	5.00	5.00	5.00	1.13	1.33	1.08	1.02	1.07	0.92
	I	1.00	1.00	1.00	3.41	3.29	2.82	5.00	5.00	5.00	1.13	1.23	1.11	1.08	1.22	0.97
	J	1.00	1.00	1.00	3.55	3.81	3.06	5.00	5.00	5.00	1.22	1.10	1.16	1.05	0.90	1.28
	K	1.00	1.00	1.00	3.45	3.76	3.08	5.00	5.00	5.00	1.13	1.10	1.10	0.97	0.89	1.14
	L	1.00	1.00	1.00	3.67	3.63	3.08	5.00	5.00	5.00	1.22	1.13	1.02	0.98	0.94	1.07
	M	1.00	1.00	1.00	3.66	3.80	3.02	5.00	5.00	5.00	1.19	1.02	1.25	0.96	0.79	1.38
	N	1.00	1.00	1.00	3.59	3.24	2.90	5.00	5.00	5.00	1.10	1.21	0.80	0.89	1.12	0.62
Subcontractor / main contractor	A	1.00	1.00	1.00	2.99	2.95	2.67	5.00	5.00	5.00	1.16	1.09	1.09	0.96	0.92	1.06
	B	1.00	1.00	1.00	3.17	3.56	3.06	5.00	5.00	5.00	1.34	0.95	1.25	1.34	0.81	1.52
	C	1.00	1.00	1.00	3.15	3.51	2.47	5.00	5.00	5.00	1.38	1.11	1.08	1.31	1.00	0.97
	D	1.00	1.00	1.00	3.16	3.69	3.02	5.00	5.00	5.00	1.24	0.98	1.16	1.37	0.78	1.44
	E	1.00	1.00	1.00	2.81	3.37	2.63	5.00	5.00	5.00	1.33	1.10	1.30	1.24	1.04	1.28
	F	1.00	1.00	1.00	2.88	3.50	2.29	5.00	5.00	5.00	1.24	1.14	1.14	1.09	1.03	1.41
	G	1.00	1.00	1.00	2.66	2.96	2.59	5.00	5.00	5.00	1.30	1.13	1.21	1.29	0.98	1.09
	H	1.00	1.00	1.00	3.13	3.22	2.63	5.00	5.00	5.00	1.24	1.30	0.93	1.42	1.32	0.83
	I	1.00	1.00	1.00	3.10	3.13	2.51	5.00	5.00	5.00	1.20	1.23	0.92	1.30	1.44	0.88
	J	1.00	1.00	1.00	3.32	3.47	2.92	5.00	5.00	5.00	1.24	1.14	1.08	1.34	1.09	1.02
	K	1.00	1.00	1.00	3.20	3.42	3.12	5.00	5.00	5.00	1.14	1.10	0.97	1.22	1.02	1.12
	L	1.00	1.00	1.00	3.10	3.53	2.71	5.00	5.00	5.00	1.28	1.01	0.87	1.46	0.88	0.80
	M	1.00	1.00	1.00	3.51	3.36	3.08	5.00	5.00	5.00	1.19	1.03	1.13	1.01	1.02	1.26
	N	1.00	1.00	1.00	3.45	3.19	2.98	5.00	5.00	5.00	1.08	1.26	0.75	1.01	1.27	0.50

Table 4 [cd]

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Investor / investor's representative	A	1.00	1.00	1.00	3.51	3.03	2.65	5.00	5.00	5.00	1.10	1.08	0.97	1.02	1.36	0.78
	B	1.00	1.00	1.00	3.60	3.66	3.37	5.00	5.00	5.00	1.22	1.01	1.01	1.05	0.86	0.87
	C	1.00	1.00	1.00	3.08	3.44	2.59	5.00	5.00	5.00	1.28	1.16	1.10	1.37	1.11	1.09
	D	1.00	1.00	1.00	3.37	3.73	3.14	5.00	5.00	5.00	1.16	1.06	1.22	1.28	0.92	1.42
	E	1.00	1.00	1.00	3.29	3.45	3.06	5.00	5.00	5.00	1.20	1.09	1.05	1.26	0.95	1.19
	F	1.00	1.00	1.00	3.49	3.74	2.59	5.00	5.00	5.00	1.20	1.10	0.93	1.12	0.85	0.81
	G	1.00	1.00	1.00	3.05	3.20	2.78	5.00	5.00	5.00	1.29	1.14	1.10	1.33	1.15	0.99
	H	1.00	1.00	1.00	3.86	3.37	2.96	5.00	5.00	5.00	0.96	1.29	0.96	0.76	1.18	0.79
	I	1.00	1.00	1.00	3.54	3.53	2.78	5.00	5.00	5.00	1.06	1.18	0.98	1.04	1.00	0.86
	J	1.00	1.00	1.00	3.90	3.70	3.33	5.00	5.00	5.00	1.06	1.09	0.99	0.75	0.86	1.08
	K	1.00	1.00	1.00	3.72	3.47	3.31	5.00	5.00	5.00	0.97	1.06	1.02	0.76	0.99	1.08
	L	1.00	1.00	1.00	3.88	3.63	3.12	5.00	5.00	5.00	0.98	1.09	0.97	0.77	0.90	1.32
	M	1.00	1.00	1.00	3.97	3.67	3.06	5.00	5.00	5.00	1.07	1.08	0.97	0.79	0.91	1.19
	N	1.00	1.00	1.00	3.75	3.33	3.37	5.00	5.00	5.00	1.04	1.25	0.70	0.83	1.15	0.88

of all the determined functions are presented in Table 4. Analysis of all the diagrams (analysis of function shapes) allows for a conclusion that it is the *gauss2mf* function that models the expert assessment distributions (assessment histograms) best. Appropriate symbols were adopted in the formulas below and in Table 4 with the calculated parameter values. The formula of the *trimf* type membership function:

$$f(x, a_{\min}, a_{sr}, a_{\max}) = \left\{ \begin{array}{ccc} 0 & for & x \leq a_{\min} \\ \dfrac{x - a_{\min}}{a_{sr} - a_{\min}} & for & a_{\min} \leq x \leq a_{sr} \\ \dfrac{a_{\max} - x}{a_{\max} - a_{sr}} & for & a_{sr} \leq x \leq a_{\max} \\ 0 & for & x \geq a_{\max} \end{array} \right\} \tag{3.14}$$

The formula of the *gaussmf* type membership function:

$$f(x, a_\sigma, a_{sr}) = e^{\frac{-(x-a_{sr})^2}{2 \cdot a_\sigma^2}} \tag{3.15}$$

The formula of the *gauss2mf* type membership function:

$$f\left(x, a_{sr}, a_\sigma, a_\gamma\right) = \left\{ \begin{array}{ccc} e^{\frac{-(x-a_{sr})^2}{2 \cdot a_\sigma^2}} & for & x < a_{sr} \\ 1 & for & x = a_{sr} \\ e^{\frac{-(x-a_{sr})^2}{2 \cdot a_\gamma^2}} & for & x > a_{sr} \end{array} \right\} \tag{3.16}$$

3.3. DETERMINATION OF ASSESSMENT OF THE PARTNERING RELATIONS OF CONSTRUCTION ENTERPRISES IN THE SELECTED REGIONS

One of the goals of the present study is to propose methods of assessing the partnering relations of construction enterprises (Fig. 4) and to choose the preferred method. Apart from statistics, fuzzy sets were also proposed for the assessment of partnering relations. The author elaborated a method to determine a fuzzy set describing expert assessments and analysed the results for different types of fuzzy operations (types of functions, methods, types of defuzzification, types of fuzzy actions). The diagram in Figure 5 presents the determination of partnering relation assessment with fuzzy methods.

Fuzzy actions may be defined in different ways. In the MatLab package, two definitions were implemented for the "or" action and two definitions for the „*and*" action. The definitions of these actions are as follows:

The *or* (∪) action:

– of the *max* type

$$(\mathrm{mf}_{\mathrm{A}} \cup mf_B)(x) = \max\{mf_A(x), mf_B(x)\} \tag{3.17}$$

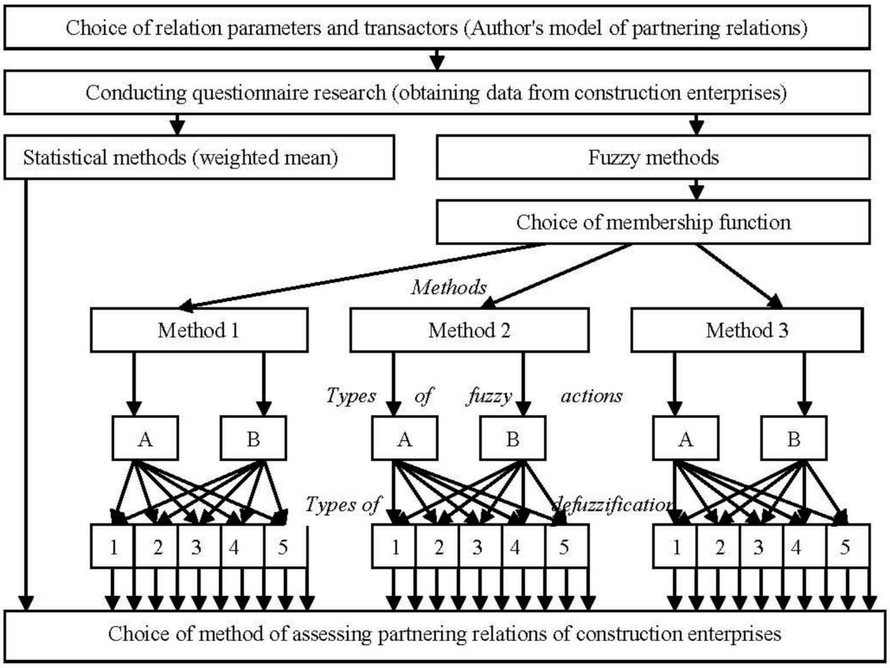

Fig. 4. The overall diagram presenting the choice of the metod to assess the partnering relations of construction enterprises (description of the adopted methods 1,2,3, types of fuzzy actions A,B, types of defuzzification 1,2,3,4,5 is to be found in the text and in Table 5).
Rys. 4. Ogólny schemat wyboru metody oceny relacji partnerskich przedsiębiorstw budowlanych (opis przyjętych metod 1,2,3, typów działań rozmytych A,B, typów defuzyfikacji 1,2,3,4,5 znajduje się w tekście oraz tabeli 5)

– of the *probor* type

(3.18) $$(\mathrm{mf}_A \cup mf_B)(x) = mf_A(x) + mf_B(x) - mf_A(x) \cdot mf_B(x).$$

The *or* (∩) action:
– of the *min* type

(3.19) $$(\mathrm{mf}_A \cap mf_B)(x) = \min\{mf_A(x), mf_B(x)\}$$

– of the *product* type

(3.20) $$(\mathrm{mf}_A \cap mf_B)(x) = mf_A(x) \cdot mf_B(x).$$

The basic methods of anti-fuzzification (defuzzification) are as follows: *centroid, bisector, mom, som, lom*. The defuzzification method of the *centroid* type consists in

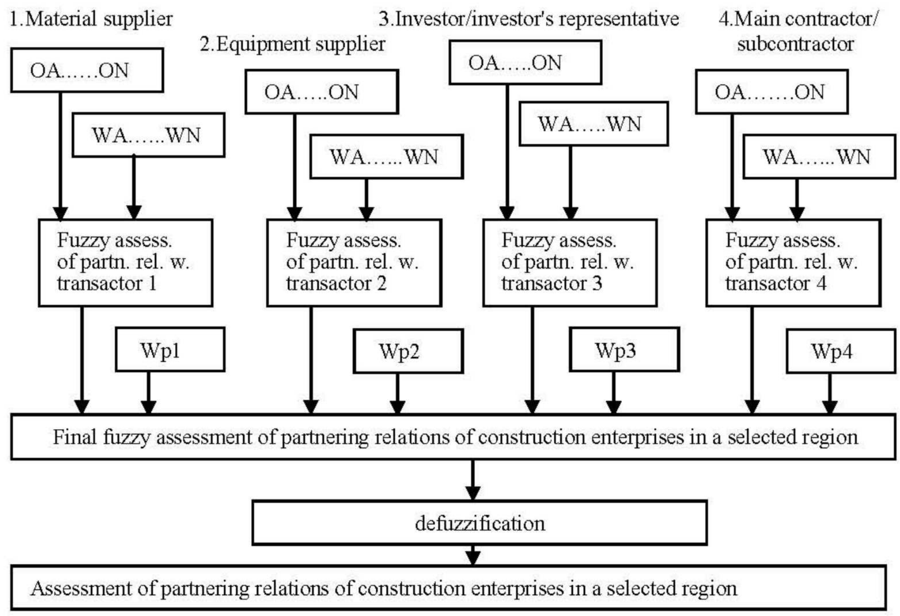

Fig. 5. Overall diagram of determination of partnering relation assessment with fuzzy methods
Rys. 5. . Ogólny schemat wyznaczenia oceny relacji partnerskich metodami rozmytymi
OA.........ON - fuzzy assessments of parameters A......N for a selected transactor and region
WA.........WN - fuzzy assessments of parameter importance A.......N for a selected transactor and region
Wp1,Wp2, Wp3, Wp4 - fuzzy assessments of transactor importance 1 - material supplier,......4 - subcontractor

determination of the integral of the resulting membership functions *mf* according to the following formula:

(3.21)
$$x_{defuz} = \frac{\int_{x_{\min}}^{x_{\max}} x \cdot mf(x)\,dx}{\int_{x_{\min}}^{x_{\max}} mf(x)\,dx}$$

The defuzzification method of the *bisector* type consists in determination of such a value x that the area under the membership function to the left and right side of this value are equal, which is expressed by the formula below:

(3.22)
$$\int_{x_{\min}}^{x_{defuz}} mf(x)\,dx = \int_{x_{defuz}}^{x_{\max}} mf(x)\,dx$$

The defuzzification method of the *mom* type consists in determination of the mean value $x$from the range in which the membership function assumes the maximum value,

which is expressed by the formula below:
(3.23)

$$x_{defuz} = \frac{\max\left\{x \in [x_{\min}, x_{\max}] : mf(x) = \max_{xp}\{mf(xp)\}\right\} + \min\left\{x \in [x_{\min}, x_{\max}] : mf(x) = \max_{xp}\{mf(xp)\}\right\}}{2}$$

The defuzzification method of the *som* type consists in determination of the minimum value $x$for which the membership function assumes the maximum value, which is expressed by the formula below:

$$x_{defuz} = \min\left\{x \in [x_{\min}, x_{\max}] : mf(x) = \max_{xp}\{mf(xp)\}\right\} \tag{3.24}$$

The defuzzification method of the *lom* type consists in determination of the maximum value $x$for which the membership function assumes the maximum value, which is expressed by the formula below:

$$x_{defuz} = \max\left\{x \in [x_{\min}, x_{\max}] : mf(x) = \max_{xp}\{mf(xp)\}\right\} \tag{3.25}$$

The author proposed three methods of assessing the partnering relations of construction enterprises with four transactors on institutional markets, using the fuzzy action and defuzzification methods described above. The first method assumed that particular assessments of the parameters which describe partnering relations with selected transactors are fuzzy sets but their weights are not fuzzy. The average assessment of the importance $\bar{x}_j^{(wag)}$ of particular parameters is determined according to the formula:

$$\bar{x}_j^{(wag)} = \frac{1}{n}\sum_{i=1}^{n} x_{i,j}^{(wag)} \tag{3.26}$$

where:

$x_{i,j}^{(wag)}$ – assessment of importance of the *j-th* relation parameter for the *i-th* construction enterprise.

The average assessments of the importance of particular parameters, determined according to the above formula, cannot be used directly as weighted coefficients because they are not in the 0 to 1 scale, and their sum does not equal 1. Consequently, the mean values of assessment of each of fourteen relation parameters (in the 1 to 5 scale) were replaced by fourteen weighted coefficients $w_j^{(wag)}$ (in the 0 to 1 scale) according to the Author's formula:

$$(3.27)\quad w_j^{(wag)} = \begin{cases} \dfrac{\bar{x}_j^{(wag)} - \min\limits_{j=1,\ldots,m}\left\{\bar{x}_j^{(wag)}\right\}}{\sum\limits_{j=1}^{m}\bar{x}_j^{(wag)}} & \text{for} \quad \min\limits_{j=1,\ldots,m}\left\{\bar{x}_j^{(wag)}\right\} \neq \max\limits_{j=1,\ldots,m}\left\{\bar{x}_j^{(wag)}\right\} \\ \dfrac{1}{m} & \text{for} \quad \min\limits_{j=1,\ldots,m}\left\{\bar{x}_j^{(wag)}\right\} = \max\limits_{j=1,\ldots,m}\left\{\bar{x}_j^{(wag)}\right\} \end{cases}$$

where:

m – the number of relation parameters.

The fuzzy set of relation parameter assessment in the first method is as follows

$$(3.28)\qquad \mu^{(k)} = \sum_{j=1}^{n} w_j^{(wag)} \cdot \mu_j^{(k)}$$

where:

$\mu^{(k)}$ – the resultant set of assessment for the k-th transactor,

$\mu_j^{(k)}$ – the membership function of the fuzzy set determining the expert assessment distribution of the j-th parameter for the k-th transactor;

$w_j^{(wag)}$ – the weighted coefficient for the j-th parameter.

The second method assumed that both particular assessments of parameters describing partnering relations with selected transactors and their weights are fuzzy sets. The resultant fuzzy set of partnering relation assessment in the second method is expressed by the formula:

$$(3.29)\qquad \mu^{(k)} = \sum_{j=1}^{n} \mu_j^{(wag)} \wedge \mu_j^{(k)}$$

The third method assumed that both particular assessments of parameters describing partnering relations with selected transactors and their weights are fuzzy sets. Additionally, there is a fuzzy set (with the membership function μ_{kor} which determines the satisfactory level of partnering relations in a construction enterprise (Fig. 6).

The formula (3.30) makes it possible to determine the fuzzy set of partnering relation assessment in the third method.

$$(3.30)\qquad \mu^{(k)} = \sum_{j=1}^{n} \mu_j^{(wag)} \wedge \mu_j^{(k)} \wedge \mu_{kor}$$

In each of the methods, the resultant assessment of the level of partnering relations $rp^{(k)}$ in a construction enterprise is determined with the use of the defuzzification operation.

$$(3.31)\qquad rp^{(k)} = defuzz\left(\mu^{(k)}\right)$$

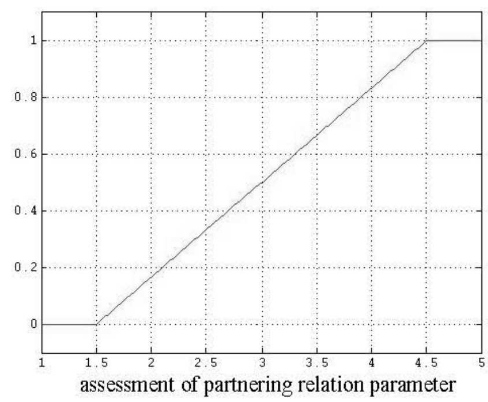

Fig. 6. The shape of the membership function of the fuzzy set determining the satisfactory level of partnering relations.
Rys. 6. Kształt funkcji przynależności zbioru rozmytego określającego zadawalający poziom relacji partnerskich

where:
$\mu^{(k)}$ – fuzzy assessment of partnering relations for the *k- th* transactor.

The fuzzy sets of assessment were determined for each of the transactors with all three methods for two variants of the fuzzy action types *or, and,* respectively *min, max* and *probor, product*. Additionally, in each of the above variants, the membership functions for parameter assessments were determined on the basis of the triangle membership function, the membership function based on the Gauss distribution and the membership function based on the asymmetrical Gauss distribution; the following defuzzification methods were used: *centroid, bisector, mom, som, lom* (Table 5).

In order to compare the results obtained by fuzzy and statistical methods, the weighted mean was calculated as well. This was achieved by determining the mean assessments of particular relation parameters for each transactor according to the formula:

$$\bar{x}_j^{(k)} = \frac{1}{n}\sum_{j=1}^{n} x_{i,j}^{(k)} \qquad (3.32)$$

where:
$x_{i,j}^{(k)}$ – assessment by the expert from the *i-th* construction enterprises for the *j-th* relation parameter and the *k-th* transactor,

n – the number of examined construction enterprises in a given country.

Table 5

Types of membership functions, methods, defuzzification types and fuzzy action types, adopted for calculations.

WPrzyjęte do obliczeń typy funkcji przynależności, metody, typy defuzyfikacji oraz typy działań rozmytych

Membership function types	**Methods**	**Defuzzification types**	**Fuzzy action types**
1. *trimf* 2. *gaussmf* 3. *gauss2mf*	1. Assessments of parameters describing partnering relations with selected transactors are fuzzy sets while their weights are not fuzzy 2. Both assessments of parameters describing partnering relations with selected transactors and their weights are fuzzy sets. 3. Both assessments of parameters describing partnering relations with selected transactors and their weights are fuzzy sets. Additionally, there is a fuzzy set which determines the satisfactory level of partnering relations in a construction enterprise	1.*centroid* weight centre method 2.*bisector* modal value method (symmetral area) 3.*mom* maximum middle method (mean of maximum values) 4.*som* first maximum method (the lowest of the maximum values) 5. *lom* last maximum method (the highest of the maximum values)	A. action *or* as *max, and* as *min* B. action *or* as *probor, and* as *product*

The average assessment of the partnering relations of construction enterprises with each of the transactors is determined according to the formula:

$$\bar{x}^{(k)} = \frac{1}{m} \sum_{j=1}^{m} x_j^{(k)} \cdot w_j^{(wag)} \tag{3.33}$$

Calculations were done for the classical approach (the weighted mean of the average assessments) and for the fuzzy logic approach. All research results obtained with fuzzy methods are presented in Tables 6-9. The bold type of font marks the lowest and the highest resultant assessment of partnering relations determined with fuzzy methods for particular transactors and countries. The highlighted background of the results in the tables indicates the method preferred by the author. The choice of this method is justified later in the paper.

Assessment of the partnering relations of Polish construction enterprises with material suppliers (Tab. 6), determined with the weighted mean method, amounts to 3.43 whereas the lowest value obtained with fuzzy methods is 3.12, and the highest one is 4.00. The value obtained with the preferred method is 3.7. Assessment of the partnering relations of Slovak construction enterprises with material suppliers, determined with the weighted mean method, amounts to 3.52 whereas the lowest value obtained with fuzzy methods is 3.08, and the highest one is 3.96. The value obtained with the preferred method is 3.63. Assessment of the partnering relations of Ukrainian construction enterprises with material suppliers, determined with the weighted mean method, amounts to 2.88 whereas the lowest value obtained with fuzzy methods is

Table 6

Assessment of the partnering relations of Polish (P), Slovak (S) and Ukrainian (U) construction enterprises with material suppliers, determined with different fuzzy methods.
Ocena relacji partnerskich polskich (P), słowackich (S) i ukraińskich(U) przedsiębiorstw budowlanych z dostawcami materiałów wyznaczona różnymi metodami rozmytymi

Defuzzification type	Function type	Action type	Method 1			Method 2			Method 3		
			P	S	U	P	S	U	P	S	U
centroid	*trimf*	A	3.20	3.17	2.95	3.22	3.17	3.09	3.42	3.41	3.35
		B	**3.12**	3.15	2.95	3.56	3.52	3.22	3.59	3.56	3.25
	gaussmf	A	3.22	3.19	2.94	3.80	3.50	3.29	3.80	3.59	3.38
		B	3.23	3.29	2.93	3.76	3.67	3.29	3.79	3.71	3.32
	gauss2mf	A	3.19	**3.08**	2.92	3.67	3.32	3.28	3.68	3.56	3.39
		B	3.16	3.16	2.89	3.61	3.53	3.29	3.65	3.58	3.32
bisektor	*trimf*	A	3.28	3.22	2.93	3.31	3.24	3.12	3.49	3.48	3.40
		B	3.17	3.20	2.94	3.58	3.54	3.23	3.60	3.57	3.25
	gaussmf	A	3.30	3.24	2.91	3.84	3.55	3.32	3.86	3.67	3.44
		B	3.28	3.36	2.92	3.76	3.67	3.29	3.80	3.71	3.32
	gauss2mf	A	3.26	3.12	2.90	3.74	3.38	3.27	3.75	3.64	3.44
		B	3.20	3.21	2.88	3.61	3.54	3.29	3.66	3.58	3.32
mom	*trimf*	A	3.66	3.81	2.74	3.67	3.50	3.26	3.77	3.73	3.56
		B	3.38	3.49	2.90	3.63	3.60	3.21	3.63	3.66	3.23
	gaussmf	A	3.66	3.81	**2.74**	3.86	3.58	3.35	**4.00**	**3.96**	**3.73**
		B	3.44	3.57	2.88	3.76	3.68	3.29	3.80	3.71	3.32
	gauss2mf	A	3.66	3.81	**2.74**	3.82	3.53	3.28	3.98	3.94	3.67
		B	3.42	3.49	2.86	3.70	3.63	3.27	3.74	3.67	3.31
som	*trimf*	A	3.66	3.81	**2.74**	3.67	3.50	3.26	3.77	3.73	3.56
		B	3.38	3.49	2.90	3.63	3.60	3.21	3.63	3.66	3.23
	gaussmf	A	3.66	3.81	**2.74**	3.86	3.58	3.35	**4.00**	3.96	3.73
		B	3.44	3.57	2.88	3.76	3.68	3.29	3.80	3.71	3.32
	gauss2mf	A	3.66	3.81	**2.74**	3.82	3.53	3.28	3.98	3.94	3.67
		B	3.42	3.49	2.86	3.70	3.63	3.27	3.74	3.67	3.31
lom	*trimf*	A	3.66	3.81	**2.74**	3.67	3.50	3.26	3.77	3.73	3.56
		B	3.38	3.49	2.90	3.63	3.60	3.21	3.63	3.66	3.23
	gaussmf	A	3.66	3.81	**2.74**	3.86	3.58	3.35	**4.00**	**3.96**	**3.73**
		B	3.44	3.57	2.88	3.76	3.68	3.29	3.80	3.71	3.32
	gauss2mf	A	3.66	3.81	**2.74**	3.82	3.53	3.28	3.98	3.94	3.67
		B	3.42	3.49	2.86	3.70	3.63	3.27	3.74	3.67	3.31

2.74, and the highest one is 3.73. The value obtained with the preferred method is 3.27. Assessment of the partnering relations of Polish and Slovak construction enterprises with material suppliers is comparable and slightly higher than in Ukrainian enterprises, where there is no clear advantage of the partnering relations over the traditional ones.

Table 7

Assessment of the partnering relations of Polish (P), Slovak (S) and Ukrainian (U) construction enterprises with equipment suppliers, determined with different fuzzy methods.
Ocena relacji partnerskich polskich (P), słowackich (S) i ukraińskich(U) przedsiębiorstw budowlanych z dostawcami maszyn wyznaczona różnymi metodami rozmytymi

Defuzzification type	Function type	Action type	Method 1			Method 2			Method 3		
			P	S	U	P	S	U	P	S	U
centroid	*trimf*	A	3.10	3.14	2.93	3.22	3.17	3.09	3.42	3.41	3.35
		B	**3.04**	**3.10**	2.89	3.55	3.51	3.22	3.58	3.55	3.25
	gaussmf	A	3.10	3.17	2.88	3.80	3.50	3.29	3.80	3.59	3.38
		B	3.07	3.21	2.86	3.75	3.66	3.28	3.78	3.70	3.31
	gauss2mf	A	3.07	3.08	2.95	3.67	3.32	3.28	3.68	3.56	3.39
		B	3.06	3.15	2.86	3.60	3.52	3.28	3.64	3.57	3.31
bisektor	*trimf*	A	3.15	3.19	2.91	3.31	3.24	3.12	3.49	3.48	3.40
		B	3.05	3.14	2.86	3.57	3.53	3.22	3.60	3.56	3.25
	gaussmf	A	3.17	3.22	2.85	3.84	3.55	3.32	3.86	3.67	3.44
		B	3.08	3.25	2.84	3.75	3.66	3.28	3.78	3.70	3.31
	gauss2mf	A	3.13	3.12	2.92	3.74	3.38	3.27	3.75	3.64	3.44
		B	3.08	3.18	2.83	3.60	3.53	3.28	3.65	3.58	3.31
mom	*trimf*	A	3.51	3.47	**2.63**	3.67	3.50	3.26	3.77	3.73	3.56
		B	3.13	3.37	2.71	3.63	3.59	3.21	3.63	3.60	3.23
	gaussmf	A	3.51	3.47	**2.63**	3.86	3.58	3.35	**4.00**	**3.96**	**3.73**
		B	3.14	3.38	2.78	3.75	3.66	3.28	3.78	3.70	3.31
	gauss2mf	A	3.51	3.47	**2.63**	3.82	3.53	3.28	3.98	3.94	3.67
		B	3.12	3.34	2.78	3.69	3.62	3.26	3.73	3.66	3.30
som	*trimf*	A	3.51	3.47	**2.63**	3.67	3.50	3.26	3.77	3.73	3.56
		B	3.13	3.37	2.71	3.63	3.59	3.21	3.63	3.60	3.23
	gaussmf	A	3.51	3.47	**2.63**	3.86	3.58	3.35	**4.00**	**3.96**	**3.73**
		B	3.14	3.38	2.78	3.75	3.66	3.28	3.78	3.70	3.31
	gauss2mf	A	3.51	3.47	**2.63**	3.82	3.53	3.28	3.98	3.94	3.67
		B	3.12	3.34	2.78	3.69	3.62	3.26	3.73	3.66	3.30
lom	*trimf*	A	3.51	3.47	**2.63**	3.67	3.50	3.26	3.77	3.73	3.56
		B	3.13	3.37	2.71	3.63	3.59	3.21	3.63	3.60	3.23
	gaussmf	A	3.51	3.47	**2.63**	3.86	3.58	3.35	**4.00**	**3.96**	**3.73**
		B	3.14	3.38	2.78	3.75	3.66	3.28	3.78	3.70	3.31
	gauss2mf	A	3.51	3.47	**2.63**	3.82	3.53	3.28	3.98	3.94	3.67
		B	3.12	3.34	2.78	3.69	3.62	3.26	3.73	3.66	3.30

Assessment of the partnering relations of Polish construction enterprises with equipment suppliers (Tab. 7), determined with the weighted mean method, amounts to 3.13 whereas the lowest value obtained with fuzzy methods is 3.04, and the highest one is 4.00. The value obtained with the preferred method is 3.69. Assessment of the partnering relations of Slovak construction enterprises with equipment suppliers, determined with the weighted mean method, amounts to 3.35 whereas the lowest value obtained with fuzzy methods is 3.1, and the highest one is 3.96. The value obtained with the preferred method is 3.62. Assessment of the partnering relations of Ukrainian construction enterprises with equipment suppliers, determined with the weighted mean method, amounts to 2.77 whereas the lowest value obtained with fuzzy methods is 2.63, and the highest one is 3.73. The value obtained with the preferred method is 3.26. Assessment of the partnering relations of Polish and Slovak construction enterprises with equipment suppliers is comparable and slightly higher than in Ukrainian enterprises, where there is no clear advantage of the partnering relations over the traditional ones.

Assessment of the partnering relations of Polish construction enterprises with main contractors/subcontractors (Tab. 8), determined with the weighted mean method, amounts to 3.58 whereas the lowest value obtained with fuzzy methods is 3.17, and the highest one is 4.0. The value obtained with the preferred method is 3.71. Assessment of the partnering relations of Slovak construction enterprises with main contractors/subcontractors, determined with the weighted mean method, amounts to 3.50 whereas the lowest value obtained with fuzzy methods is 3.14, and the highest one is 3.96. The value obtained with the preferred method is 3.63. Assessment of the partnering relations of Ukrainian construction enterprises with main contractors/subcontractors, determined with the weighted mean method, amounts to 3.01 whereas the lowest value obtained with fuzzy methods is 3.0, and the highest one is 3.73. The value obtained with the preferred method is 3.28. Assessment of the partnering relations of Polish and Slovak construction enterprises with main contractors/subcontractors is comparable and slightly higher than in Ukrainian enterprises, where there is no clear advantage of the partnering relations over the traditional ones.

Assessment of the partnering relations of Polish construction enterprises with investors/investor representatives (Tab. 9), determined with the weighted mean method, amounts to 3.46 whereas the lowest value obtained with fuzzy methods is 3.11, and the highest one is 4.0. The value obtained with the preferred method is 3.7. Assessment of the partnering relations of Slovak construction enterprises with investors/investor representatives, determined with the weighted mean method, amounts to 3.51 whereas the lowest value obtained with fuzzy methods is 3.15, and the highest one is 3.96. The value obtained with the preferred method is 3.63. Assessment of the partnering relations of Ukrainian construction enterprises with investors/investor representatives, determined with the weighted mean method, amounts to 3.08 whereas the lowest value obtained with fuzzy methods is 3.01, and the highest one is 3.73. The value obtained with the preferred method is 3.28. Assessment of the partnering relations of Polish and Slovak construction enterprises with investors/investor representatives is comparable

Table 8

Assessment of the partnering relations of Polish (P), Slovak (S) and Ukrainian (U) construction enterprises with main contractors/subcontractors, determined with different fuzzy methods.
Ocena relacji partnerskich polskich (P), słowackich (S) i ukraińskich(U) przedsiębiorstw budowlanych z głównymi wykonawcami/podwykonawcami wyznaczona różnymi metodami rozmytymi

Defuzzification type	Function type	Action type	Method 1			Method 2			Method 3		
			P	S	U	P	S	U	P	S	U
centroid	*trimf*	A	3.24	3.17	3.00	3.22	3.17	3.09	3.42	3.41	3.35
		B	**3.17**	**3.14**	3.02	3.57	3.52	3.23	3.60	3.55	3.26
	gaussmf	A	3.26	3.25	2.98	3.80	3.50	3.29	3.80	3.59	3.38
		B	3.33	3.29	3.01	3.77	3.67	3.29	3.80	3.71	3.33
	gauss2mf	A	3.24	3.19	3.01	3.67	3.32	3.28	3.68	3.56	3.39
		B	3.24	3.21	3.01	3.62	3.53	3.29	3.66	3.58	3.33
bisektor	*trimf*	A	3.31	3.22	**3.00**	3.31	3.24	3.12	3.49	3.48	3.40
		B	3.22	3.20	3.02	3.59	3.54	3.24	3.62	3.57	3.26
	gaussmf	A	3.34	3.30	2.98	3.84	3.55	3.32	3.86	3.67	3.44
		B	3.40	3.35	3.01	3.77	3.67	3.29	3.80	3.70	3.32
	gauss2mf	A	3.32	3.24	3.01	3.74	3.38	3.27	3.75	3.64	3.44
		B	3.30	3.26	3.02	3.62	3.54	3.29	3.67	3.58	3.33
mom	*trimf*	A	3.96	3.70	3.06	3.67	3.50	3.26	3.77	3.73	3.56
		B	3.51	3.45	3.06	3.63	3.60	3.22	3.63	3.63	3.23
	gaussmf	A	3.96	3.70	3.06	3.86	3.58	3.35	**4.00**	3.96	**3.73**
		B	3.63	3.51	3.04	3.77	3.67	3.29	3.80	3.70	3.32
	gauss2mf	A	3.96	3.70	3.06	3.82	3.53	3.28	3.98	3.94	3.67
		B	3.57	3.49	3.03	3.71	3.63	3.28	3.75	3.66	3.32
som	*trimf*	A	3.96	3.70	3.06	3.67	3.50	3.26	3.77	3.73	3.56
		B	3.51	3.45	3.06	3.63	3.60	3.22	3.63	3.63	3.23
	gaussmf	A	3.96	3.70	3.06	3.86	3.58	3.35	4.00	**3.96**	**3.73**
		B	3.63	3.51	3.04	3.77	3.67	3.29	3.80	3.70	3.32
	gauss2mf	A	3.96	3.70	3.06	3.82	3.53	3.28	3.98	3.94	3.67
		B	3.57	3.49	3.03	3.71	3.63	3.28	3.75	3.66	3.32
lom	*trimf*	A	3.96	3.70	3.06	3.67	3.50	3.26	3.77	3.73	3.56
		B	3.51	3.45	3.06	3.63	3.60	3.22	3.63	3.63	3.23
	gaussmf	A	3.96	3.70	3.06	3.86	3.58	3.35	**4.00**	3.96	**3.73**
		B	3.63	3.51	3.04	3.77	3.67	3.29	3.80	3.70	3.32
	gauss2mf	A	3.96	3.70	3.06	3.82	3.53	3.28	3.98	3.94	3.67
		B	3.57	3.49	3.03	3.71	3.63	3.28	3.75	3.66	3.32

and slightly higher than in Ukrainian enterprises, where there is no clear advantage of the partnering relations over the traditional ones.

Table 9

Assessment of the partnering relations of Polish (P), Slovak (S) and Ukrainian (U) construction enterprises with investors/investor representatives, determined with different fuzzy methods.
Ocena relacji partnerskich polskich (P), słowackich (S) i ukraińskich(U) przedsiębiorstw budowlanych z inwestorami/ inwestorami zastępczym wyznaczona różnymi metodami rozmytymi

Defuzzification type	Function type	Action type	Method 1			Method 2			Method 3		
			P	S	U	P	S	U	P	S	U
centroid	*trimf*	A	3.20	3.20	3.05	3.22	3.17	3.09	3.42	3.41	3.35
		B	3.13	**3.15**	3.02	3.56	3.52	3.23	3.60	3.55	3.26
	gaussmf	A	3.19	3.24	**3.01**	3.80	3.50	3.29	3.80	3.59	3.38
		B	3.25	3.31	3.05	3.76	3.67	3.30	3.80	3.71	3.33
	gauss2mf	A	**3.11**	3.21	3.01	3.67	3.32	3.28	3.68	3.56	3.39
		B	3.18	3.23	3.10	3.61	3.53	3.30	3.65	3.58	3.34
bisektor	*trimf*	A	3.27	3.27	3.07	3.31	3.24	3.12	3.49	3.48	3.40
		B	3.18	3.20	3.03	3.58	3.54	3.24	3.61	3.57	3.26
	gaussmf	A	3.27	3.30	3.04	3.84	3.55	3.32	3.86	3.67	3.44
		B	3.30	3.36	3.06	3.76	3.67	3.30	3.80	3.70	3.33
	gauss2mf	A	3.18	3.27	3.03	3.74	3.38	3.27	3.75	3.64	3.44
		B	3.22	3.28	3.11	3.62	3.54	3.30	3.66	3.58	3.34
mom	*trimf*	A	3.86	3.85	3.16	3.67	3.50	3.26	3.77	3.73	3.56
		B	3.43	3.47	3.10	3.63	3.60	3.22	3.63	3.60	3.23
	gaussmf	A	3.86	3.85	3.16	3.86	3.58	3.35	**4.00**	**3.96**	3.73
		B	3.48	3.53	3.10	3.76	3.67	3.30	3.80	3.70	3.33
	gauss2mf	A	3.86	3.85	3.16	3.82	3.53	3.28	3.98	3.94	3.67
		B	3.44	3.50	3.11	3.70	3.63	3.28	3.74	3.66	3.32
som	*trimf*	A	3.86	3.85	3.16	3.67	3.50	3.26	3.77	3.73	3.56
		B	3.43	3.47	3.10	3.63	3.60	3.22	3.63	3.60	3.23
	gaussmf	A	3.86	3.85	3.16	3.86	3.58	3.35	4.00	3.96	**3.73**
		B	3.48	3.53	3.10	3.76	3.67	3.30	3.80	3.70	3.33
	gauss2mf	A	3.86	3.85	3.16	3.82	3.53	3.28	3.98	3.94	3.67
		B	3.44	3.50	3.11	3.70	3.63	3.28	3.74	3.66	3.32
lom	*trimf*	A	3.86	3.85	3.16	3.67	3.50	3.26	3.77	3.73	3.56
		B	3.43	3.47	3.10	3.63	3.60	3.22	3.63	3.60	3.23
	gaussmf	A	3.86	3.85	3.16	3.86	3.58	3.35	4.00	3.96	3.73
		B	3.48	3.53	3.10	3.76	3.67	3.30	3.80	3.70	3.33
	gauss2mf	A	3.86	3.85	3.16	3.82	3.53	3.28	3.98	3.94	3.67
		B	3.44	3.50	3.11	3.70	3.63	3.28	3.74	3.66	3.32

To sum up, the maximum difference between the result obtained with different fuzzy methods amounts to 1 on a 5-point scale. This is a significant difference, affecting the interpretation of the final result. Thus, the preferred method turned out to be the correct one and the result obtained with this method was the most credible. The choice of the preferred method has the following justification. The type of membership function which expresses the reply frequency diagrams best is the *gauss2mf* function. The *mom* method was adopted as a method of defuzzification. This method consists in determination of an assessment for which the degree of membership in the resultant fuzzy set is maximum. In the case when there are several assessments whose membership degrees equal the maximum membership degree, the mean of these assessments is adopted as the assessment. Because the membership functions describing the fuzzy assessments of particular characteristics are matched to the reply frequency diagrams, the degree of membership for a given assessment (the value of the membership function for this assessment) corresponds to the percentage of replies. In this case, a degree of membership may be treated as a degree of certainty. By choosing the *mom* defuzzification method one assumes that the resultant assessment is one with the highest degree of certainty. The use of this defuzzification method makes it possible to reduce the influence on the final assessment of the extreme assessments. When the *centroid* method is used, this influence is quite significant. The resultant assessments of partnering relations obtained with the use of the following actions: *min, max* as well as *product, probor* differ slightly. Further analysis used actions of the B type, i.e. *product, probor*, because these are the closest to the classical product and to the sum used for the calculation of the weighted mean. Out of the analysed methods, the second one was selected as it takes into consideration the fuzzy character of both parameter assessment and parameter importance.

The author's own method, selected in this way, was then used to determine the assessment of the partnering relations of construction enterprises in each of the analysed regions of the three countries. For the purposes of comparison, assessment of partnering relations was performed in each region also with the use of the Baas and Kwakernaak method and with the statistical method (the weighted mean).

Calculations with the preferred, author's own method were done according to the following formula:

$$\mu = \sum_{k=1}^{k_p} w_k^{(wag)} \wedge \mu^{(k)} \tag{3.34}$$

$$\bar{x} = defuzz\left(\mu\right) \tag{3.35}$$

Assessment of the partnering relations of construction enterprises in a selected region of a given country, using the Baas and Kwakernaak method, may be established using the following formula:

(3.36)

$$\mu\left(x\right) = \max\left\{\min\left\{\mu_1^{(wag)}\left(x\right), \mu^{(1)}\left(x\right)\right\}, \ldots, \min\left\{\mu_k^{(wag)}\left(x\right), \mu^{(k)}\left(x\right)\right\}, \ldots, \min\left\{\mu_{k_p}^{(wag)}\left(x\right), \mu^{(k_p)}\left(x\right)\right\}\right\}$$

$$\bar{x} = defuzz(\mu) \tag{3.37}$$

The average weighted assessment of the level of the partnering relations of construction enterprises in a selected region of a given country may be established using the following formula:

$$\bar{x} = \frac{1}{k_p}\sum_{k=1}^{k_p} x^{(k)} \cdot w_k^{(wag)} \tag{3.38}$$

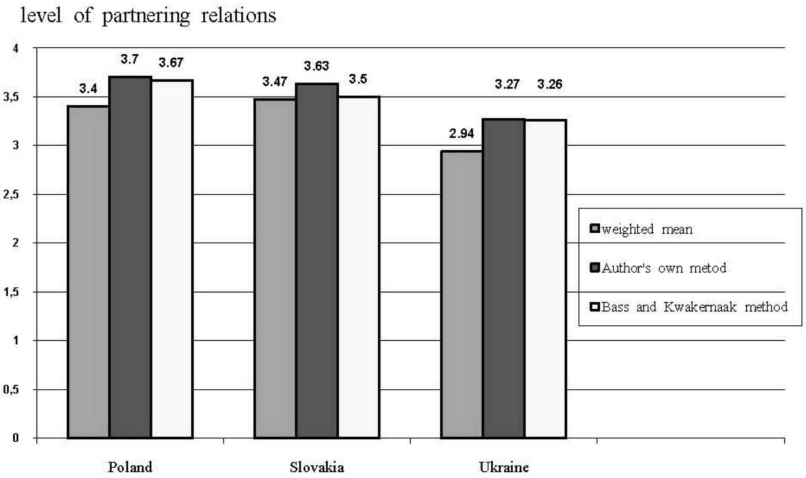

Fig. 7. Assessment of the partnering relations of Polish (P), Slovak (S) and Ukrainian (U) construction enterprises determined with different methods (the Author's own method being the preferred one).
Rys. 7. Ocena relacji partnerskich polskich, słowackich i ukraińskich przedsiębiorstw budowlanych wyznaczona różnymi metodami (preferowana – metoda własna)

The final results are presented in Fig. 7. The results obtained with the author's preferred method are regarded as the most reliable.

4. Conclusions

For all of the analysed regions in the selected countries, the assessment of the partnering relations of construction enterprises determined with the statistical method is lower than the assessment of the partnering relations determined with two selected methods based on fuzzy logic (Fig. 7). The maximum difference between the results obtained with the methods used here for a given region was 0.4 for Ukrainian construction enterprises. It may be assumed that almost half a point on a five-point scale constitutes a significant difference. The maximum difference between the results obtained with the two methods based on fuzzy logic amounted to 0.1. This case may be treated as an insignificant difference. The results obtained with the statistical methods and the fuzzy methods do differ whereas the results obtained with selected fuzzy methods do not differ significantly. The result obtained with the fuzzy methods is, on the basis of the analysis presented above, more reliable.

The assessment of the partnering relations of Polish and Slovak construction enterprises is similar and oscillates around grade 3.5; when determined with the author's own method it is, respectively, 3.7 for Polish enterprises and 3.63 for Slovak ones. This means that partnering co-operation is already noticeable but still weak in the construction industry. The results obtained with the methods based on fuzzy logic indicate a slightly higher level of partnering relations in Polish construction enterprises than in Slovak ones. Assessment of the partnering relations of Ukrainian construction enterprises is lower than that of Polish and Slovak ones and oscillates around grade 3.0. This assessment, determined with the author's own method, amounts to 3.27. This assessment may be considered as neutral on the five-point scale ranging from 1-traditional relations to 5-partnering relations. This means that Ukrainian construction enterprises are not undertaking noticeable partnering co-operation although typically traditional relations are not clearly visible there either.

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METODYKA OCENY RELACJI PARTNERSKICH POLSKICH, SŁOWACKICH I UKRAIŃSKICH PRZEDSIĘBIORSTW BUDOWLANYCH Z WYKORZYSTANIEM LOGIKI ROZMYTEJ

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

W artykule przedstawiono metodykę badania i oceny relacji partnerskich przedsiębiorstw budowlanych z zastosowaniem statystyki oraz logiki rozmytej. Zaprezentowano wyniki badań przeprowadzonych w polskich, słowackich i ukraińskich przedsiębiorstwach budowlanych. Definicja partnerstwa w budownictwie wskazuje, że jest to pojęcie jakościowe. Poprzez zastosowanie skali w kwestionariuszu wywiadu oraz matematyczną analizę zebranych danych, ostateczny wynik przeprowadzonych badań przedstawiający poziom relacji partnerskich przedsiębiorstw budowlanych jest ujęty ilościowo. W pracy uzasadniono wybór preferowanej przez autorkę metody rozmytej.

Końcowa ocena relacji partnerskich polskich i słowackich przedsiębiorstw budowlanych jest podobna, wyznaczona różnymi metodami oscyluje wokół oceny 3.5, wyznaczona preferowaną metodą własną wynosi odpowiednio dla polskich przedsiębiorstw budowlanych 3.7 i słowackich 3.63. Oznacza to, że wprawdzie jest już widoczna, ale jeszcze słabo, współpraca partnerska w budownictwie. Ocena relacji partnerskich w ukraińskich przedsiębiorstwach budowlanych jest niższa niż w przedsiębiorstwach słowackich i ukraińskich i oscyluje wokół oceny 3.0. Wyznaczona preferowaną metodą własną wynosi 3.27. Można powiedzieć, że ocena ta jest oceną neutralną na skali pięciostopniowej od 1- relacje tradycyjne do 5- relacje partnerskie. Oznacza to, że ukraińskie przedsiębiorstwa budowlane nie podejmują widocznej współpracy partnerskiej, a jednocześnie relacje typowo tradycyjne też nie są wyraźnie widoczne.

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