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FUZZY CONTROL OF PARTNERING RELATIONS OF A CONSTRUCTION ENTERPRISE

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Abstract. The author has elaborated an expert system to control partnering relations with a construction enterprise. The expert system is based on Mamdani fuzzy model. The purpose of the system is to improve the indices of assessing a construction enterprise by raising the level of partnering relations with other transactors in industry. The system indicates a recommendation supporting a decision-making system of any given construction enterprise and stating whether relations are to be preserved, changed or changed immediately to each of the fourteen relation parameters and for each of four transactors of enterprise's microenvironment. For every relation parameter, this decision is taken by the expert system with reference to the significance and assessment of this parameter identifying its influence on the success of a construction enterprise. Another task of the expert system is to select one parameter for each transactor which needs to be changed first. The process of choosing the parameter to be changed first for a given transactor is based on all input parameters.

Keywords: construction enterprise, microenvironment, partnering, partnering relations, fuzzy control, expert system.

1. Introduction

In the report "In Search of Partnering Excellence" produced by Construction Industry Institute in 1991 the following definition was proposed. 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 understanding each other's individual expectations and values. The expected benefits include improved efficiency and cost effectiveness, increased opportunity for innovation and continuous improvement in quality products and services" (CII 1991). The report is based on 27 case studies concerning partnering co-operation in the USA.

The same year, 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 where people accept responsibility for their actions. Partnering is not a business contract as it is recognition that every contract includes an implied covenant of good faith" (AGC 1991).

The former definition given by CII describes "strategic partnering" while the latter one provided by AGC defines "project partnering". In construction industry, one can apply a short-term partnering approach, i.e. partnering co-operation in a single construction project, or a strategic partnering approach, which is a long-term process extending over several investments. What is important is that project partnering constitutes the first step towards long-term co-operation, i.e. strategic partnering.

The analysis of relevant literature allows the author to note that, in the subject of partnering relations, one can distinguish several themes and that this phenomenon is developing differently in some countries. The largest number of studies has been produced in the USA, Great Britain, Australia and Hong Kong. The amount of project partnering analyses is larger than that of strategic partnering. Relevant research trends concerning partnering, as distinguished by the present author, are described below.

Most studies are the results of research on particular construction projects (Shields and West 2003; Franke and Grebenc 2008; Eriksson and Nilsson 2008; Chan *et al.* 2003; Baxendale and Greaves 1997; Drexler and Larson 2000; Gransberg *et al.* 1999). Successful strategic partnering is described, for example, by Kaluarachchi and Jones (2007) and Eom *et al.* (2008).

Some of the case studies do not arrive at unequivocally positive conclusions concerning partnering, e.g. (Bresnen and Marshall 2000; Kululanga *et al.* 2001). However, they all emphasize a considerably smaller number of misunderstandings in the partnering approach. Bresnen and Marshall (2000) have presented a general review of the problems encountered by partnering enterprises.

Some papers dealing with partnering assume a point of view of one of the parties involved in a construction project: the main contractor or subcontractor, supplier and client (Wood and Ellis 2005; Mason 2007; Dainty *et al*. 2001; Arditi and Chotibhongs 2005; Eriksson *et al*. 2008; Latham 1994). The currently valid aspects of choosing contractors and subcontractors are analyzed in, among other papers, publications by Plebankiewicz (2010) and Ulubeyli *et al*. (2010). Plebankiewicz (2009) applies the fuzzy set theory to model the procedure of the pre-qualification of construction work contractors.

Many authors have aimed at analyzing the process of partnering, including the distinction of its features on the basis of particular construction projects or particular enterprises, e.g. (Yeung *et al*. 2007, 2008; Eriksson and Pesämaa 2007). A system of partnering assessment has been proposed, for example, by Cheung *et al*. (2003a), Bayliss *et al*. (2004), Nyström (2008), Cheng and Li (2004). Beach *et al*. (2005) assess the progress of British construction industry in the implementation of the partnering approach. These authors predict that the partnering trend in construction industry is going to last. Among works on partnering in British construction industry, a study by Black *et al*. (2000) should be mentioned.

Finding success factors in partnering was the aim of research carried out in Hong Kong (Chan *et al.* 2004). Chen and Chen (2007) analyzed these factors looking at a partnering project conducted in Taiwan. Success factors were also studied by Tang *et al*. (2006). Bubshait (2001) emphasizes that partnering is a method of cost reduction minimizing conflicts between project participants.

Crucial work, describing the seven pillars of partnering in construction industry, is a book by Bennett and Jayes (1998). It is frequently referred to by other authors, e.g. (Bresnen 2007). Among theoretical works are ones stressing that trust is the most important factor of successful partnering, e.g. (Cheung *et al*. 2003b; Cheung 2007; Kumaraswamy *et al*. 2005).

Besides, there are analyses of partnering making the use of the game theory and the prisoner's dilemma, e.g. (Sacks and Harel 2006) or (Wong *et al*. 2005). Another approach uses social network analysis (Pryke 2004). Information exchange in the partnering project is dealt in the papers by Drejer and Vinding (2006), Chan *et al*. (2005) and Lipshitz *et al*. (2002).

A remarkably large number of studies have been conducted on the Far East markets, e.g. (Phua and Rowlinson 2004; Kwan and Ofori 2001). Work by Koraltan and Dikbas (2002) describes an aspect that affects partnering in construction industry in Turkey. Ng *et al*. (2002) as well as Glagola and Sheedy (2002) examine the development of partnering in construction projects commissioned by the Australian government.

To sum up, the review of literature shows that although partnering as a strategy in construction industry is relatively new, its concept has already spread over very different and often very distant parts of the world. As noted by numerous authors, this is a new approach particularly novel in construction industry where competition is deeply rooted, and therefore those enterprises implementing partnering encounter the whole range of problems. Thus, there is no wonder that apart from optimistic works that promote project partnering, strategic partnering and describe the advantages of this approach, a number of studies point to various problems, including both internal (concerning project participants) and external (e.g. legal) ones, which partnering enterprises have to face.

Many studies argue that partnering in construction industry is an interdisciplinary phenomenon. All works mentioned in the present paper have one common characteristic, namely, none of them claims that partnering is an unsuitable approach for construction industry. All predict that partnering will develop in the future.

The present author's own papers on the subject also need to be mentioned. A full review of models in which partnering has a key part as well as her personal model of partnering relations in construction industry are presented in Radziszewska-Zielina (2008c). Barriers to creating partnering relations by Polish construction enterprises and advantages of using the partnering approach in construction industry are described in Radziszewska-Zielina (2008b). The characteristics of construction enterprise's activity on the market are shown in Radziszewska-Zielina (2008a).

There are few publications concerning partnering relations in European countries. However, this new trend is already visible in works on marketing. For instance, an article by Virvilaitė (2008) focuses on a new concept in marketing, namely relation marketing. Long-term relations between an enterprise and its client based on trust and client satisfaction constitute a new trend currently followed in Lithuania. The author regards the assessment of client satisfaction as the basic method of examining relations between an enterprise and a client.

The present paper aims at proposing a fuzzy expert system to manage partnering relations in any given construction enterprise. Supporting engineering activity and construction processes by means of expert systems has been discussed, among others, by Kapliński and Zavadskas (1997). Kapliński (2008) notes the use of computer methods in decision making by construction enterprises. The techniques of planning and decision making are developing. The application of expert systems in Poland remained a comparable level in 1990 and 2005, as noted by Kapliński (2008) whereas in the European Union, the application of fuzzy computer systems is increasing (see Kapliński 2008, Fig. 1). According to the author, the methods described in his article are still used by Polish enterprises insufficiently. In another paper (Kapliński 2009), concerning the application made by Polish construction enterprises dealing with various IT systems that aid in information flow and facilitate enterprise's cooperation with its environment, the author notes the dynamic development of IT tools used for enterprise management and project management, including the use of expert systems. He states that the experience of construction enterprises shows that, in order to function effectively, they have to integrate their management systems with the environment. This goal is achieved *via* such measures as cooperation with suppliers, subcontractors and investors. Kapliński *et al*. (2002) point to the relation between a construction enterprise and the microenvironment as one of three basic research topics related to the organization and management of construction enterprises.

The main aim of research and analyses carried out by the author is to increase the effectiveness of construction enterprises (including time effectiveness and reduction of costs connected with the implementation of construction projects) by managing relations with transactors in the environment in order to create partnering relations. Although fuzzy logic has been applied by other authors in engineering construction enterprises, e.g. in order to solve the problem of selecting a contractor by the investor, yet it has not been used in the context of creating partnering relations with the contractor. The fuzzy expert system that manages the partnering relations of a construction enterprise is elaborated by the author as her novel contribution to the issue of partnering in construction industry. When analyzing the available works on the subject, the author has not encountered a similar approach.

2. A Project of the Expert System

The expert system introduced in the present paper is based on Mamdani fuzzy model. Fig. 1 presents the structure of Mamdani sample fuzzy system having two inputs and one output.

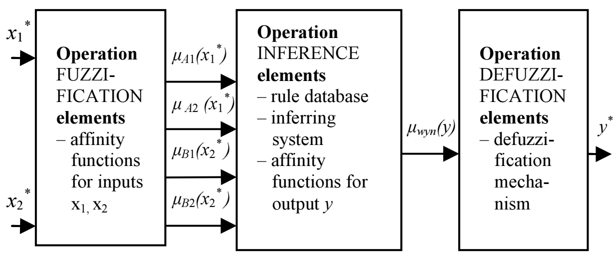

Fig. 1. The structure of the sample fuzzy system with inputs and 1 output (Piegat 2003)

The fuzzy set input is crisp values x_1^* and x_2^*. In the FUZZIFICATION section, the operation of fuzzification occurs, i.e. calculating the degree of affinity with particular fuzzy sets A_i, B_j of the inputs. The FUZZIFICATION section must possess the defined functions of affinity with the fuzzy sets of particular inputs $\mu_{Ai}(x_1)$ and $\mu_{Bj}(x_2)$.

The INFERENCE section calculates, on the basis of the input degrees of affinity $\mu_{Ai}(x_1^*)$ and $\mu_{Bj}(x_2^*)$, the resulting function of affinity $\mu_{result}(y)$ of the model output calculated by means of inference realization. The INFERENCE section must have the defined rule database, an inferring system and functions of the affinity of the model output. The database contains the rules of logic which determine cause-and-effect relations existing in the system between the input and output fuzzy sets. The inferring system calculates resultant affinity function $\mu_{result}(y)$. This system consists of the following parts:

1) a part calculating the degree of fulfilling the prerequisites of particular rules;
2) a part calculating the degree of making the conclusions of particular rules active;
3) a part determining the resultant form of the function of input affinity $\mu_{result}(y)$ on the basis of degrees of making the conclusions of particular rules active.

The algorithm of inference according to Piegat (2003) is presented below in the paper.

The purpose of inference is determining the resultant function of affinity $\mu_{result}(y)$ of the database conclusion.

A database in the form of 'if-and-then' conjunction containing *m* rules (1) is given:

$$R1: IF(x_1=A_{11}) AND \ldots AND (x_i=A_{1i}) AND \ldots AND (x_n=A_{1n}) THEN (y=B_1),$$
$$\vdots$$
$$Rj: IF(x_1=A_{j1}) AND \ldots AND (x_i=A_{ji}) AND \ldots AND (x_n=A_{jn}) THEN (y=B_j),$$
$$\vdots$$
$$Rm: IF(x_1=A_{m1}) AND \ldots AND (x_i=A_{mi}) AND \ldots AND (x_n=A_{mn}) THEN (y=B_m), \quad (1)$$

where $A_{11,\ldots} A_{ji,\ldots} A_{mn}$ – fuzzy sets of prerequisites; $B_{1,\ldots}$ B_m – fuzzy sets of conclusions; $x_{1,\ldots} x_n$ – the input magnitudes of the fuzzy model; x_1^*, x_2^* – the values of the input magnitudes of the model; y – the output magnitude of the model.

Step 1. The determination of fulfilment degree *h* of the prerequisites of particular rules according to prerequisite aggregation formula (2):

$$h_1=T(\mu_{A11}(x_1^*), \ldots \mu_{A1n}(x_n^*)),$$
$$\vdots$$
$$h_j=T(\mu_{Aj1}(x_1^*), \ldots \mu_{Ajn}(x_n^*)),$$
$$\vdots$$
$$h_m=T(\mu_{Am1}(x_1^*), \ldots \mu_{Amn}(x_n^*)), \quad (2)$$

where *T* is one of *t-norm* operators (realization *and* operation). According to experts (Pfeiffer 1996), a *product* is the most frequently used operator.

Step 2. The determination of the modified affinity functions $\mu_{B*j}(y)$ of conclusions concerning particular rules (3):

$$\mu_{B1*}(y)=T(h_1, \mu_{B1}(y)),$$
$$\vdots$$
$$\mu_{Bj*}(y)=T(h_j, \mu_{Bj}(y)),$$
$$\vdots$$
$$\mu_{Bm*}(y)=T(h_m, \mu_{Bm}(y)). \quad (3)$$

The operation is performed only for activated rules the prerequisites of which are fulfilled to degree h>0. Non-activated rules (h = 0) do not take part in the inference.

Step 3. The determination of resultant affinity function $\mu_{result}(y)$ by means of accumulating the modified functions of affinity $\mu_{Bj*}(y)$ of conclusions of particular rules according to formula (4):

$$\mu_{result}(y)=\mu_{B*}(y)=S(\mu_{B1*}(y), \ldots \mu_{Bm*}(y)), \quad (4)$$

where *S* signifies one of s-*norms* (realization *or* operation), e.g. *max* while $B^*=B_1^* \cup \ldots \cup B_m^*$ is the fuzzy set of the database resultant conclusion.

The DEFUZZIFICATION section, on the basis of the resultant function of output affinity $\mu_{result}(y)$, calculates the crisp value of the output resulting from providing the crisp values of inputs x_1^*, x_2^* to the model.

The author has elaborated an expert system designed to control partnering relations in a construction enterprise. The aim of the system is to improve the indices of construction enterprise assessment by raising the level of partnering relations with transactors in the environment cooperating on the institutional market. A block diagram of a control system is presented in Fig. 2.

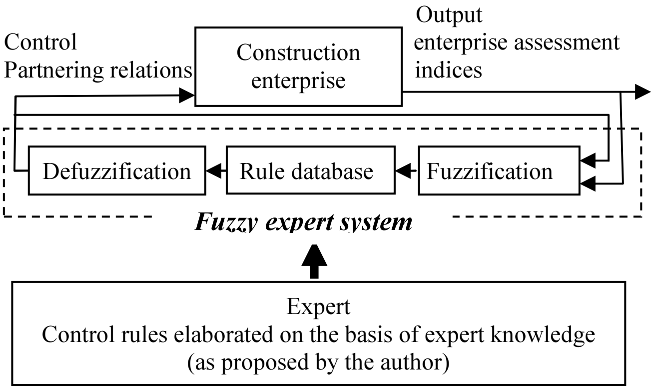

Fig. 2. The diagram showing the functioning of the fuzzy expert system based on the Mamdani model

In the present author's project on an expert system, inputs x_i^* are adopted as an assessment of parameters taking into account relations O_A…O_N, considering significance W_A…W_N and the impact on construction enterprise's success S_A…S_N. Outputs y_i^* include $W_{nA}…W_{nN}$ (in rule database Wn_N) determining whether a given level of relations should be preserved, changed or changed immediately with respect to particular parameters A…N and wn output determining which parameter ought to be changed first.

The aim of the presented expert system is to determine, for each transactor and each relation parameter, a recommendation aiding the decision-making system of any given construction enterprise which indicates whether the relations are to be preserved, changed or changed immediately. It is not possible to improve several parameters in an enterprise at the same time as this may disorganize its functioning. It is important to determine what parameter needs to be changed first. Therefore, one of the tasks of the expert system is to choose those relation parameters that require changing in the first place because they can diminish the effectiveness of enterprise functioning. The influence of particular parameters on enterprise effectiveness is assessed by means of the index of the impact on the success of an enterprise. Such assessment is performed by an expert in a construction enterprise using a scale ranging from 1 to 5 (weak impact – strong impact).

Using the five-point scale, an expert of the enterprise also assesses the significance of relation parameters (low significance – high significance) and their level (traditional relations – partnering relations).

The decision whether relations can be preserved, changed or changed immediately is taken, considering each of the parameters, by the expert system on the basis of analyzing the significance of a parameter, the assessment of a parameter and its impact on enterprise success. Choosing the given transactor of the parameter to be changed first is made referring to all input parameters. The expert system has forty-two inputs (there are fourteen relation parameters, each of which is described by significance W, assessment O and the impact on construction enterprise success S).

The indices using symbols W, O and S signify the parameters of relations from A to N. Because the scale of grades is from 1 to 5, the ranges of the adopted input variables also vary from 1 to 5. The system has 15 outputs. Each parameter is associated with one output determining the recommendation (preserve, change or change immediately) made for each parameter. The fifteenth, additional output determines which parameter should be changed first. These decisions are taken by the system on the basis of the rule database.

With regard to the control of partnering relations, fuzzy sets are used in order to determine the extent of partnering relations occurring in the contacts between a construction enterprise and particular transactors. In accordance with the classical approach, the assumption that e.g. the set of grades 1, 2 or 3 is referred to as traditional relations while 4 and 5 are accepted as partnering relations is large simplification. It is not easy to qualify grade 3 as either traditional or partnering relation. This was the reason to apply fuzzy logic, i.e. to assume that both traditional and partnering relations are described by fuzzy sets.

The expert system was constructed with the help of Mamdani model characterized by such inference rules where both the antecedent and the consequent are fuzzy. The system was modelled with the use of the fuzzy toolbox available in the MatLab package. The author used the program implementing the algorithm that realizes the method applied. Figs 3–8 below are the result of the performance of the MatLab package mentioned above; they present graphic interface used to feed the parameters of the fuzzy expert system. For this reason, the author decided to present them in the original version (as on the screen). Figs 3–8 show feeding system parameters. Operation *and* was assumed to be the *product* operation type, operation *or* was assumed to be *probor*, the type of operation for implication *product*. *Mom* was selected as the type of defuzzification preferred in decision-making systems (Fig. 3).

For the input related to parameter assessment, two fuzzy sets describing traditional and partnering relations were determined. Fully traditional relations are at level 1. For a grade equal to or higher than 3, it is assumed that these are certainly not traditional relations. Fully partnering relations are at level 5. For a grade lower than or equal to 2, relations are definitely not the partnering ones (Fig. 4).

For the input related to the significance of a parameter, two fuzzy sets, describing either low or high significance were determined. Low significance was assumed for grade 1. For a grade equal to or higher than 3, it is assumed that significance certainly is not that low. Higher significance was assumed for grade 5. For a grade equal to or smaller than 2, it is assumed that this is definitely not high significance (Fig. 5).

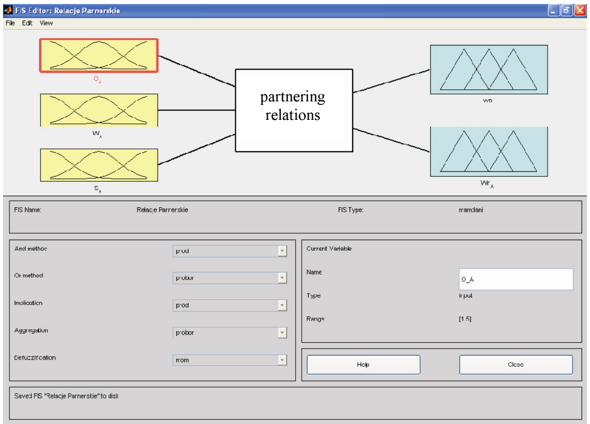

Fig. 3. The structure of the expert system for partnering relation control in a construction enterprise

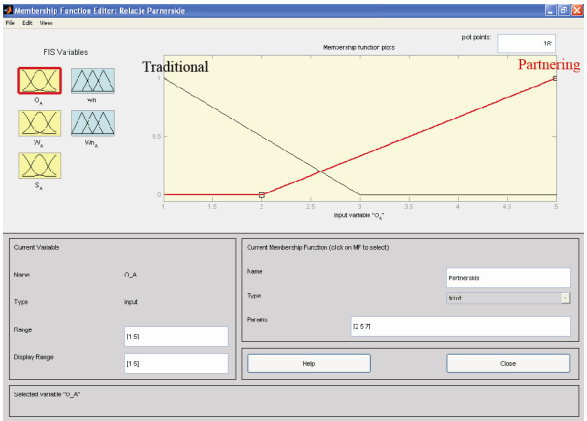

Fig. 4. Affinity functions defined for input O_A – assessment of parameter A

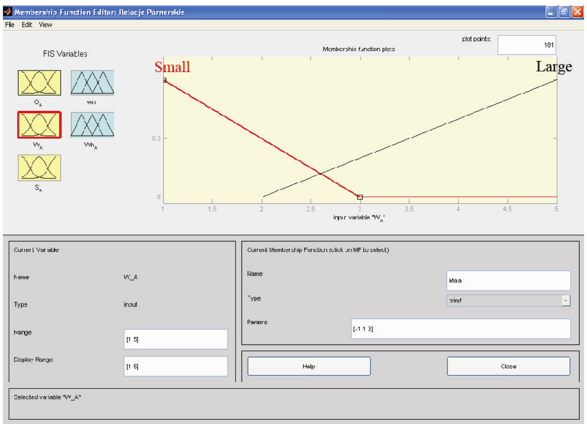

Fig. 5. Affinity functions defined for input W_A – the significance of parameter A

For the input related to the impact of a parameter on enterprise success, two fuzzy sets, describing either a weak or strong impact, were determined. A weak impact was assumed for grade 1. For a grade equal to or higher than 3, it is assumed this is certainly not weak impact. Strong impact was assumed for grade 5. For grade equal to or smaller than 2 it is assumed this is definitely not strong impact (Fig. 6).

Affinity functions were determined analogously to all other inputs.

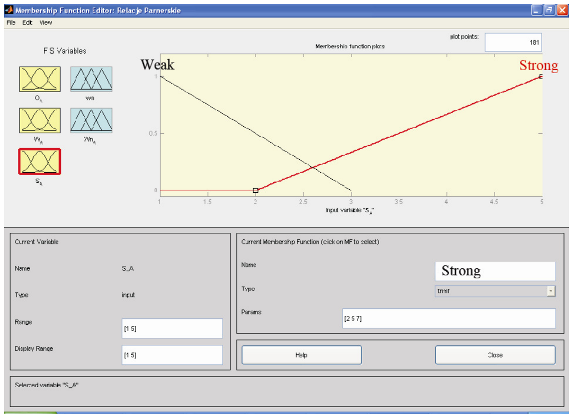

Fig. 6. Affinity functions defined for input S_A – the impact of parameter A on enterprise success

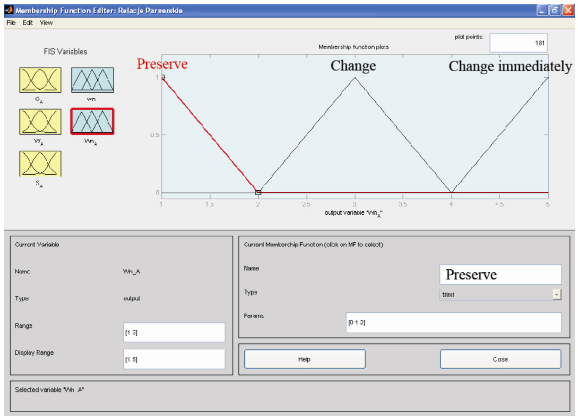

Fig. 7. Affinity functions defined for the output related to the parameter

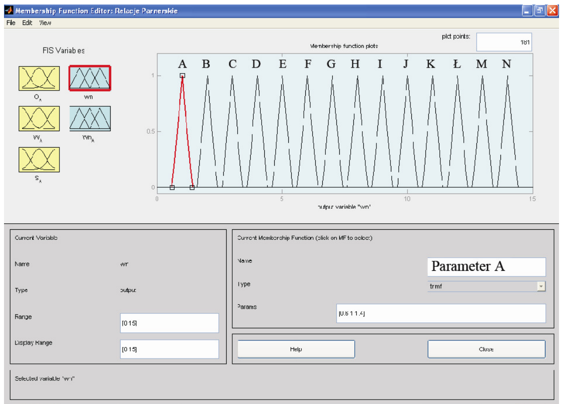

Fig. 8. The output determining the decision the parameter of which needs to be changed first

Considering the output related to the selected parameter, we want to obtain one of the three decisions: preserve relations, change relations or change relations immediately. Consequently, three affinity functions were defined, each related to one of the three decisions (Fig. 7).

Considering the output presented in Fig. 8, one obtains a subsequent number of the parameter which needs to be changed first. Numbers 1, 2, 3,… 14 refer to parameters A, B, C,…N. Affinity functions were defined in such a way as to unequivocally determine the parameter that they are related to.

In expert systems, the database is created on the basis of the expert's knowledge. In the present paper, the database was elaborated by its author on the basis of research conducted on a large sample of construction enterprises in the selected regions of three countries (Radziszewska-Zielina 2010a, 2010b) as well as following consultation with experts in these enterprises. The rule database is presented in Table 1.

Table 1. The rule database of the expert system proposed by the author

1. If (O_A is Traditional) and (W_A is Large) and (S_A is Weak) then (wn is Parameter A) (1)
2. If (O_A is Traditional) and (W_A is Large) and (S_A is Strong) then (wn is Parameter A) (1)
3. If (O_A is Traditional) and (W_A is Small) and (S_A is Weak) then (wn is Parameter A) (1)
4. If (O_A is Traditional) and (W_A is Large)and(S_A is Weak) then (Wn_N is Change immediately) (1)
5. If (O_A is Traditional) and (W_A is Large) and (S_A is Strong) then (Wn_N is Preserve) (1)
6. If (O_A is Traditional) and (W_A is Small) and (S_A is Weak) then (Wn_N is Change) (1)
7. If (O_A is Traditional) and (W_A is Small) and (S_A is Strong) then (Wn_N is Change) (1)
8. If (O_A is Partnering) then (Wn_N is Preserve) (1)
9. If (O_B is Traditional) and (W_B is Large) and (S_B is Weak) then (wn is Parameter B) (1)
10. If (O_B is Traditional) and (W_B is Large) and (S_B is Strong) then (wn is Parameter B) (1)
11. If (O_B is Traditional) and (W_B is Small) and (S_B is Weak) then (wn is Parameter B) (1)
12. If(O_B is Traditional) an (W_B is Large) and (S_B is Weak) then (Wn_N is Change immediately) (1)
13. If (O_B is Traditional) and (W_B is Large) and (S_B is Strong) then (Wn_N is Preserve) (1)
14. If (O_B is Traditional) and (W_B is Small) and (S_B is Weak) then (Wn_N is Change) (1)
15. If (O_B is Traditional) and (W_B is Small) and (S_B is Strong) then (Wn_N is Change) (1)
16. If (O_B is Partnering) then (Wn_N is Preserve) (1)
17. If (O_C is Traditional) and (W_C is Large) and (S_C is Weak) then (wn is Parameter C) (1)
18. If (O_C is Traditional) and (W_C is Large) and (S_C is Strong) then (wn is Parameter C) (1)
19. If (O_C is Traditional) and (W_C is Small) and (S_C is Weak) then (wn is Parameter C) (1)
20. If(O_C is Traditional) and (W_C is Large) and (S_C is Weak) then (Wn_N is Change immediately) (1)
21. If (O_C is Traditional) and (W_C is Large) and (S_C is Strong) then (Wn_N is Preserve) (1)
22. If (O_C is Traditional) and (W_C is Small) and (S_C is Weak) then (Wn_N is Change) (1)
23. If (O_C is Traditional) and (W_C is Small) and (S_C is Strong) then (Wn_N is Change) (1)
24. If (O_C is Partnering) then (Wn_N is Preserve) (1)
25. If (O_D is Traditional) and (W_D is Large) and (S_D is Weak) then (wn is Parameter D) (1)
26. If (O_D is Traditional) and (W_D is Large) and (S_D is Strong)then (wn is Parameter D) (1)
27. If (O_D is Traditional) and (W_D is Small) and (S_D is Weak) then (wn is Parameter D) (1)
28. If(O_D is Traditional) and (W_D is Large) and (S_D is Weak) then (Wn_N is Change immediately) (1)
29. If (O_D is Traditional) and (W_D is Large) and (S_D is Strong) then(Wn_N is Preserve) (1)
30. If (O_D is Traditional) and (W_D is Small) and (S_D is Weak) then (Wn_N is Change) (1)
31. If (O_D is Traditional) and (W_D is Small) and (S_D is Strong) then (Wn_N is Change) (1)
32. If (O_D is Partnering) then (Wn_N is Preserve) (1)
33. If (O_E is Traditional) and (W_E is Large) and (S_E is Weak) then (wn is Parameter E) (1)
34. If (O_E is Traditional) and (W_E is Large) and (S_E is Strong) then (wn is Parameter E) (1)
35. If (O_E is Traditional) and (W_E is Small) and (S_E is Weak) then (wn is Parameter E) (1)
36. If(O_E is Traditional) and (W_E is Large)and(S_E is Weak) then (Wn_N is Change immediately) (1)
37. If (O_E is Traditional) and (W_E is Large) and (S_E is Strong) then (Wn_N is Preserve) (1)
38. If (O_E is Traditional) and (W_E is Small) and (S_E is Weak) then (Wn_N is Change) (1)
39. If (O_E is Traditional) and (W_E is Small) and (S_E is Strong) then (Wn_N is Change) (1)
40. If (O_E is Partnering) then (Wn_N is Preserve) (1)
41. If (O_F is Traditional) and (W_F is Large) and (S_F is Weak) then (wn is Parameter F) (1)
42. If (O_F is Traditional) and (W_F is Large) and (S_F is Strong) then (wn is Parameter F) (1)
43. If (O_F is Traditional) and (W_F is Small) and (S_F is Weak) then (wn is Parameter F) (1)
44. If(O_F is Traditional) and (W_F is Large)and (S_F is Weak) then (Wn_N is Change immediately) (1)
45. If (O_F is Traditional) and (W_F is Large) and (S_F is Strong) then (Wn_N is Preserve) (1)
46. If (O_F is Traditional) and (W_F is Small) and (S_F is Weak) then (Wn_N is Change) (1)
47. If (O_F is Traditional) and (W_F is Small) and (S_F is Strong) then (Wn_N is Change) (1)
48. If (O_F is Partnering) then (Wn_N is Preserve) (1)
49. If (O_G is Traditional) and (W_G is Large) and (S_G is Weak) then (wn is Parameter G) (1)
50. If (O_G is Traditional) and (W_G is Large) and (S_G is Strong)then (wn is Parameter G) (1)
51. If(O_G is Traditional) and (W_G is Small)and (S_G is Weak) then (wn is Parameter G) (1)
52. If(O_G is Traditional) and (W_G is Large)and(S_G is Weak) then (Wn_N is Change immediately) (1)
53. If (O_G is Traditional) and (W_G is Large) and (S_G is Strong) then (Wn_N is Preserve)(1)
54. If (O_G is Traditional) and (W_G is Small) and (S_G is Weak) then (Wn_N is Change) (1)
55. If (O_G is Traditional) and (W_G is Small) and (S_G is Strong) then (Wn_N is Change) (1)
56. If (O_G is Partnering) then (Wn_N is Preserve) (1)
57. If (O_H is Traditional) and (W_H is Large) and (S_H is Weak) then (wn is Parameter H) (1)
58. If (O_H is Traditional) and (W_H is Large) and (S_H is Strong)then (wn is Parameter H) (1)
59. If (O_H is Traditional) and (W_H is Small) and (S_H is Weak) then (wn is Parameter H) (1)
60. If(O_H is Traditional) and (W_H is Large) and (S_H is Weak) then (Wn_N is Change immediately) (1)
61. If (O_H is Traditional) and (W_H is Large) and (S_H is Strong) then (Wn_N is Preserve) 1)
62. If (O_H is Traditional) and (W_H is Small) and (S_H is Weak) then (Wn_N is Change) (1)
63. If (O_H is Traditional) and (W_H is Small) and (S_H is Strong) then (Wn_N is Change) (1)
64. If (O_H is Partnering) then (Wn_N is Preserve) (1)
65. If (O_I is Traditional) and (W_I is Large) and (S_I is Weak) then (wn is Parameter I) (1)
66. If (O_I is Traditional) and (W_I is Large) and (S_I is Strong) then (wn is Parameter I) (1)
67. If (O_I is Traditional) and (W_I is Small) and (S_I is Weak) then (wn is Parameter I) (1)
68. If (O_I is Traditional) and (W_I is Large)and (S_I is Weak) then (Wn_N is Change immediately) (1)
69. If (O_I is Traditional) and (W_I is Large) and (S_I is Strong) then (Wn_N is Preserve) (1)
70. If (O_I is Traditional) and (W_I is Small) and (S_I is Weak) then (Wn_N is Change) (1)
71. If (O_I is Traditional) and (W_I is Small) and (S_I is Strong) then (Wn_N is Change) (1)
72. If (O_I is Partnering) then (Wn_N is Preserve) (1)
73. If (O_J is Traditional) and (W_J is Large) and (S_J is Weak) then (wn is Parameter J) (1)
74. If (O_J is Traditional) and (W_J is Large) and (S_J is Strong) then (wn is Parameter J) (1)
75. If (O_J is Traditional) and (W_J is Small) and (S_J is Weak) then (wn is Parameter J) (1)
76. If (O_J is Traditional) and (W_J is Large) and (S_J is Weak) then (Wn_N is Change immediately) (1)
77. If (O_J is Traditional) and (W_J is Large) and (S_J is Strong) then (Wn_N is Preserve) (1)
78. If (O_J is Traditional) and (W_J is Small) and (S_J is Weak) then (Wn_N is Change) (1)
79. If (O_J is Traditional) and (W_J is Small) and (S_J is Strong) then (Wn_N is Change) (1)
80. If (O_J is Partnering) then (Wn_N is Preserve) (1)
81. If (O_K is Traditional) and (W_K is Large) and (S_K is Weak) then (wn is Parameter K) (1)
82. If (O_K is Traditional) and (W_K is Large) and (S_K is Strong)then (wn is Parameter K) (1)
83. If (O_K is Traditional) and (W_K is Small) and (S_K is Weak) then (wn is Parameter K) (1)
84. If(O_K is Traditional) and (W_K is Large) and (S_K is Weak) then (Wn_N is Change immediately) (1)
85. If (O_K is Traditional) and (W_K is Large) and (S_K is Strong) then (Wn_N is Preserve)(1)
86. If (O_K is Traditional) and (W_K is Small) and (S_K is Weak) then (Wn_N is Change) (1)
87. If (O_K is Traditional) and (W_K is Small) and (S_K is Strong) then (Wn_N is Change) (1)
88. If (O_K is Partnering) then (Wn_N is Preserve) (1)
89. If (O_L is Traditional) and (W_L is Large) and (S_L is Weak) then (wn is Parameter L) (1)
90. If (O_L is Traditional) and (W_L is Large) and (S_L is Strong) then (wn is Parameter L) (1)
91. If (O_L is Traditional) and (W_L is Small) and (S_L is Weak) then (wn is Parameter L) (1)
92. If(O_L is Traditional) and (W_L is Large) and (S_L is Weak) then (Wn_N is Change immediately) (1)
93. If (O_L is Traditional) and (W_L is Large) and (S_L is Strong) then (Wn_N is Preserve) (1)
94. If (O_L is Traditional) and (W_L is Small) and (S_L is Weak) then (Wn_N is Change) (1)
95. If (O_L is Traditional) and (W_L is Small) and (S_L is Strong) then (Wn_N is Change) (1)
96. If (O_L is Partnering) then (Wn_N is Preserve) (1)
97. If (O_M is Traditional) and (W_M is Large)and (S_M is Weak)then (wn is Parameter M) (1)
98. If(O_M is Traditional)and (W_M is Large)and (S_M is Strong)then (wn is Parameter M) (1)
99. If (O_M is Traditional) and (W_M is Small)and (S_M is Weak)then (wn is Parameter M) (1)
100. If(O_M is Traditional) and (W_M is Large) and (S_M is Weak) then (Wn_N is Change immediately) (1)
101. If (O_M is Traditional)and(W_M is Large)and(S_M is Strong) then(Wn_N is Preserve) (1)
102. If (O_M is Traditional) and (W_M is Small)and (S_M is Weak)then (Wn_N is Change) (1)
103. If (O_M is Traditional)and (W_M is Small)and (S_M is Strong)then (Wn_N is Change) (1)
104. If (O_M is Partnering) then (Wn_N is Preserve) (1)
105. If (O_N is Traditional) and (W_N is Large)and (S_N is Weak)then (wn is Parameter N) (1)
106. If (O_N is Traditional)and (W_N is Large)and (S_N is Strong)then (wn is Parameter N) (1)
107. If (O_N is Traditional) and (W_N is Small)and (S_N is Weak)then (wn is Parameter N) (1)
108.If (O_N is Traditional) and (W_N is Large) and (S_N is Weak) then (Wn_N is Change immediately) (1)
109. If (O_N is Traditional) and(W_N is Large)and (S_N is Strong) then(Wn_N is Preserve) (1)
110. If (O_N is Traditional) and (W_N is Small) and (S_N is Weak) then (Wn_N is Change) (1)
111. If (O_N is Traditional) and (W_N is Small) and (S_N is Strong)then (Wn_N is Change) (1)
112. If (O_N is Partnering) then (Wn_N is Preserve) (1)

The creation of rules for the outputs related to parameters was based on the following rationale. If in a given enterprise the relations were partnering ones, they should be preserved and developed because they could have a positive effect on the success of that enterprise. If the relations connected with a given parameter are traditional and its significance is high but this parameter in a given enterprise does not contribute to its success (its impact on enterprise success is weak), then, this parameter should be changed immediately. In the situation where the relations for a given parameter in an enterprise are traditional, its significance is high and these current relations significantly add to enterprise success and should be preserved despite the fact that they are traditional. If relations are traditional, their significance is low and the impact on enterprise success is weak; then, changing them into more partnering relations should be recommended. It may then turn out that their impact on enterprise success is significant.

The above remarks are presented in Fig. 9 showing the diagram of creating the rule database.

Figs 10, 11, 12 present the surfaces showing the fuzzy system controlling enterprise partnering relations. In Fig. 10, axis x shows parameter assessment, axis y – parameter significance, axis z – the output representing decision index (for the impact of a parameter on enterprise success equal to 3). In Fig. 11, axis x shows parameter significance, axis y – parameter impact on enterprise success, axis z – the output representing decision index (for parameter assessment equal to 2). In Fig. 12, axis x shows parameter assessment, axis y – parameter significance, axis z – the output representing decision index (for parameter significance equal to 3).

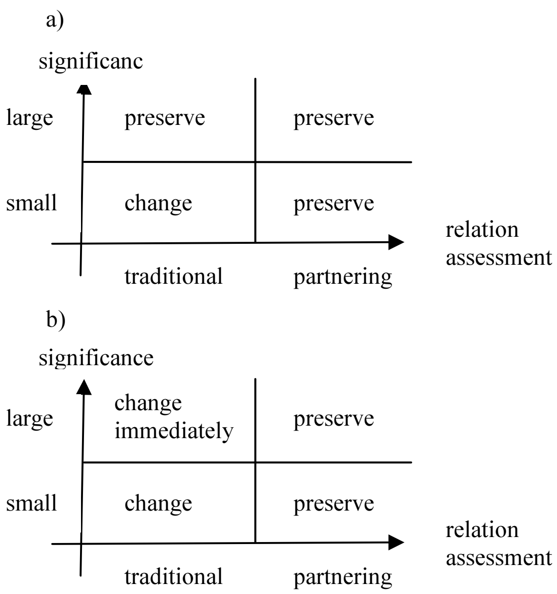

Fig. 9. The diagram of creating the rule database for a sample parameter when: a) its impact on enterprise success is strong; b) its impact on enterprise success is weak

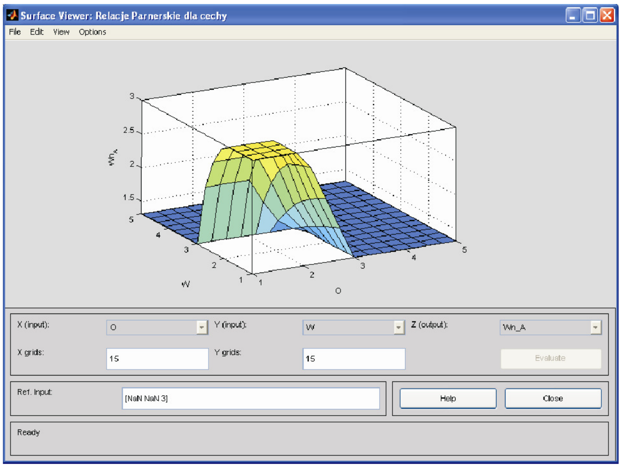

Fig. 10. The surfaces show the operation of the fuzzy system controlling enterprise partnering relations

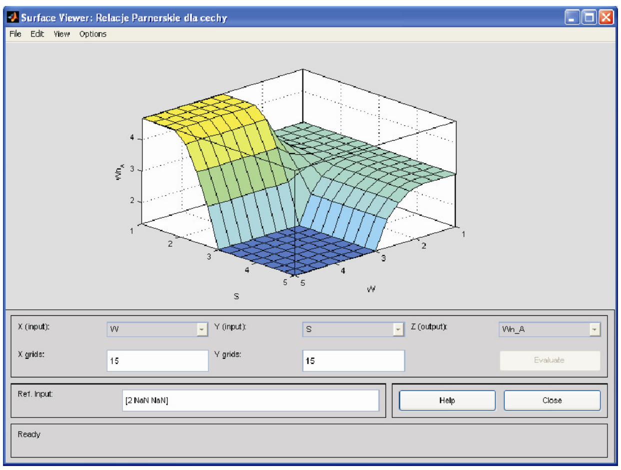

Fig. 11. The surfaces show the operation of the fuzzy system controlling enterprise partnering relations

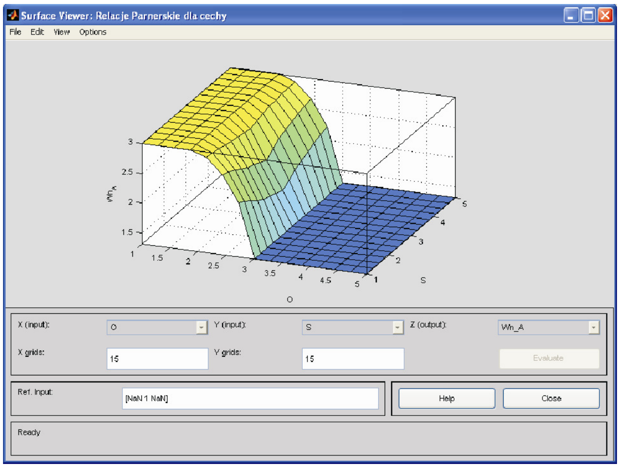

Fig. 12. The surfaces show the operation of the fuzzy system controlling enterprise partnering relations

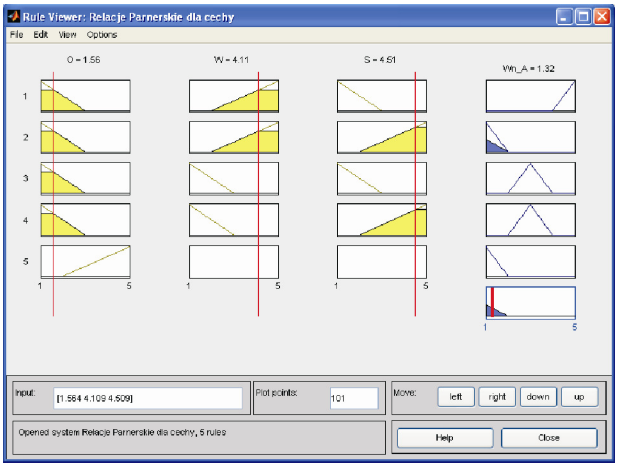

Fig. 13. The operation of a part of the fuzzy system controlling enterprise partnering relations

Fig. 13 presents the operations of five selected rules (the rules are arranged in lines) indicating which decision is to be taken for a given parameter A (preserve, change, change immediately).

The inputs for the rules include parameter assessment O, parameter significance W and impact on enterprise success S – for sample values of grades. The columns contain the graphic representations of affinity degrees of the above grades with particular fuzzy sets that occur in rule antecedents. The first five lines of the last column contain a fuzzy set which is the result of the operation of the presented rules; the red line denotes the value resulting from the operation of the defuzzification function for the resultant fuzzy set. In this case, this value denotes the decision to preserve the current relations with regard to parameter A.

3. An Example of Expert System Operation

The expert system elaborated by the author aims to aid in the decision-making process of a construction enterprise as concerns improvement in partnering relations on the institutional markets.

One Polish construction enterprise was randomly selected for analysis. The data obtained from this enterprise is provided in Table 2.

The expert system was designed by the author using the MatLab package. Calculations for the selected example were done applying ConRel *Construction Relationship Partnering* program, as commissioned by the author. The ConRel program is owned by Cracow University of Technology.

The obtained results analyzing the state of partnering relations in the examined construction enterprise with the four transactors in its microenvironment are also presented in Table 2 as a form of recommendation. One selected parameter of relations with each transactor requiring immediate improvement is presented in Table 3. The interpretation of the results may be facilitated considering the characteristics of relation parameters for a traditional and partnering approach presented by the author in the previous paper (Radziszewska-Zielina 2008c).

A parameter of "cost division" is the one the examined enterprise ought to change in the first place as concerns its relations with the selected construction material supplier or suppliers. It should therefore focus on the common and precise determination of every partner's share of costs, profit and risk related to the implementation of their contract as well as on the use of the win-win strategy. The next parameter for improvement is "sharing information": the enterprise should focus on information and experience exchange as well as on fast and open information flow. Both parameters receive recommendation "change immediately". Another two parameters that require changes include "an approach to quality control" (i.e. quality control should, mainly on the part of the supplier, be supported by trust towards its reliable partner) and "the way of communication": communication should be open, initiated by both parties, spontaneous and both personal and written (electronic) or by telephone. The remaining parameters of relations with construction material suppliers receive recommendation "preserve", i.e. at present, they may be left unchanged.

The second parameter that needs to be changed is "the basis of order placement" which is a situation when the price should not be the most important factor in selecting a supplier. The enterprise should implement a holistic approach and choose its partner with regard to such factors as a high quality of services and relations, the ability to solve problems, credibility, loyalty and a positive image. The succeeding parameters to be improved are "trust" and "the number of suppliers": the latter ought to be limited to the most trusted partners. These three parameters receive recommendation "change immediately". Another parameter that needs for changes is "the way of communication": communication should be open, initiated by both parties and spontaneous. The remaining parameters of relations with construction equipment suppliers receive recommendation "preserve", i.e. presently, they may be left unchanged.

Table 2. The grades obtained from the expert from the selected Polish construction enterprise (a scale from 1 to 5) and recommendations for this enterprise concerning the given parameters of relations with the selected transactors in the microenvironment

Relation parameter	Parameter significance	Level of relations with				Impact of parameter on success	Recommendations for relations with transactors:			
		Material supplier	Equipment supplier	Subcontractor	Investor		Material supplier	Equipment supplier	Subcontractor	Investor
Basis of order placement	5	5	1	5	4	2	Preserve	Change immediately	Preserve	Preserve
Number of suppliers/buyers	5	5	1	5	4	2	Preserve	Change immediately	Preserve	Preserve
Approach to service quality control	1	2	4	3	4	3	Change	Preserve	Preserve	Preserve
Cost division	5	1	3	2	4	2	Change immediately	Preserve	Change immediately	Preserve
Adapting to market changes	5	3	5	3	4	1	Preserve	Preserve	Preserve	Preserve
Participation in enterprise's new offer	1	4	3	2	1	3	Preserve	Preserve	Change	Change
Mutual relations	1	3	4	1	2	1	Preserve	Preserve	Change	Change
Way of communication	1	2	2	1	4	5	Change	Change	Change	Preserve
Information sharing	5	1	3	2	1	2	Change immediately	Preserve	Change immediately	Change immediately
Conflict solving	5	3	4	2	3	2	Preserve	Preserve	Change immediately	Preserve
Standards and rules of acting	5	5	3	3	2	1	Preserve	Preserve	Preserve	Change immediately
Frequency of contacts	5	5	3	3	1	2	Preserve	Preserve	Preserve	Change immediately
Approach to quality issues	5	3	4	2	4	2	Preserve	Preserve	Change immediately	Preserve
Trust	5	5	2	3	3	2	Preserve	Change immediately	Preserve	Preserve

Table 3. Recommendations for the examined construction enterprises regarding the choice of one parameter of relations with each transactor requiring immediate change

	Material supplier	Equipment supplier	Sub-contractor	Investor
Parameter name	Cost division	Basis of order placement	Cost sharing	Information sharing
Recom-mendations	Change immediately	Change immediately	Change immediately	Change immediately

The third point the examined enterprise ought to change concerning its relations with the selected construction work contractor or contractors is the parameter of "cost division". The enterprise should concentrate on the common and precise determination of every partner's share of costs, profit and risk related to the implementation of their contract as well as on the use of the win-win strategy. The following parameter that needs to be improved is "sharing information": the enterprise should focus on information and experience exchange as well as on fast and open information flow. The third parameter requiring changes is "conflict solving": the parties should work together to elaborate a common mechanism of conflict resolution.

The fourth parameter is "an approach to quality control": a complex approach to quality issues, including the quality of relations is necessary. All of the above mentioned parameters receive recommendation "change immediately". Another three parameters are to be changed next. The first one of those is: "supplier's/buyer's participation in a new offer of the enterprise" (the enterprise may have a role of a supplier/buyer in relation to the main contractor or subcontractor), i.e. active common work towards constant improvement in services. The second parameter is "mutual relations": the enterprise should focus on informal, based on trust, non-anonymous, close, individualized and multilateral relations with its subcontractors/main contractors of construction works. The third parameter is "the way of communication" that should be open, initiated by both parties and spontaneous. The remaining parameters of relations with the subcontractors/main contractors of construction works receive recommendation "preserve", i.e. at present, they may be left unchanged.

As concerns enterprise relations with the selected investors/ investor's representative, the parameter of "information sharing" should be changed first. The enterprise should therefore pay attention to the mutual exchange of information and to open and fast information flow. The next two parameters that require improvement include "standards and rules of acting" where attention should be focused on common values and goals as well as on the partners' mutual adaptation to procedures, standards, customs, ways of acting in the organization and "contact frequency" entailing attention to continual relations, repeated and lasting contacts and long-term business relations. The parameters mentioned above receive recommendation "change immediately". Another two parameters in need of change are "supplier's/buyer's participation in a new offer of the enterprise" (one should focus on active, mutual work towards constant improvement in services) and "mutual relations" (focus on informal, based on trust, non-anonymous, close, individualized and multilateral relations with investors/ investor's representative). The remaining parameters of relations with investors/ investor's representative receive recommendation "preserve", i.e. presently, they may be left unchanged.

4. Conclusions

In the present paper, the author has presented the current research trends on the basis of reviewing literature on partnering relations in construction industry. Next, the author has proposed her own expert system designed to control partnering relations of a construction enterprise. Her system has been modelled according to Mamdani fuzzy model. The aim of the system is to improve the indices of assessing a construction enterprise by increaseing the level of its partnering relations with transactors in its environment. Finally, the author of the paper has presented an example of how her expert system operates and has drawn conclusions and recommenddations for the examined sample of the Polish construction enterprise.

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STATYBOS ĮMONĖS PARTNERYSTĖS SANTYKIŲ NEAPIBRĖŽTUMO KONTROLĖ

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S a n t r a u k a

Autorė sukūrė ekspertinę sistemą, padedančią kontroliuoti partnerystės santykius statybos įmonėje. Ekspertinė sistema pagrįsta Mamdani neapibrėžtumo modeliu. Šios sistemos tikslas – pagerinti statybos įmonės rodiklius keliant partnerystės santykių su kitais pramonės dalyviais lygį. Sprendimų paramos sistema, kuri gali būti taikoma bet kurioje statybos įmonėje, teikia rekomendacijas ir nurodo, ar partnerystės santykiai su kiekvienu iš keturių įmonės mikroaplinkos dalyvių turi būti išsaugoti, ar pakeisti, ar skubiai pakeisti, atsižvelgiant į kiekvieną iš keturiolikos santykius apibrėžiančių parametrų. Ekspertinė sistema priima sprendimus pagal kiekvieną santykius apibrėžiantį parametrą, atsižvelgiant į parametro reikšmingumą statybos įmonės veiklos sėkmei. Kitas ekspertinės sistemos uždavinys – parinkti kiekvienam dalyviui po vieną santykius apibrėžiantį parametrą, kuris turi būti pakeistas pirmiausia. Parametras, kuris turi būti pakeistas pirmiausia tam tikram dalyviui yra parenkamas atsižvelgiant į visus įvesties parametrus.

Reikšminiai žodžiai: statybos įmonė, mikroaplinka, partnerystė, partnerystės santykiai, neapibrėžtumo kontrolė, ekspertinė sistema.

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