Knowledge-Based Decision Support System with Reconfiguration of Fuzzy Rule Base for Model-Oriented Academic-Industry Interaction

Yuriy P. Kondratenko(✉), Galyna V. Kondratenko, and Ievgen V. Sidenko

Department of Intelligent Information Systems, Petro Mohyla Black Sea National University, 68-th Desantnykiv Str. 10, Mykolaiv 54003, Ukraine
y_kondrat2002@yahoo.com, galvlad09@rambler.ru, emoty@mail.ru

Abstract. In this work the current state of the problem, which consists in choice the rational model of academic-industry interaction such as "University – IT-company" is analyzed. To solve this problem it is developed and researched the intelligent decision support system (DSS) based on fuzzy logic for multi-criterion evaluation the most rational model of academic-industry interaction such as "University – IT-company" in case of changing dimension of input coordinates vector.

Keywords: Decision support system · Fuzzy logic · Membership function Linguistic term · Rule base · Reconfiguration · Academic-industry interaction

1 Introduction

The essential influence on the general development and integration level of informational technologies into Ukrainian or any national economy and into world market's segments is done by results of high-efficiency and mutually profitable interaction of universities and IT-companies. Herein implementation of the new models of interaction requires consideration and preliminary processing of large amount of input data, in particular, based on analysis of preliminary interaction experience of involved parties, their main achievements, competitiveness, advantages and directions for the development, scientific and educational levels of participants of future academic-industrial consortium, employment level of students, university professors and IT-companies, etc. [1, 10]. Incorrectly chosen model of interaction as well as non-observation of relevant conditions of collaboration within the interaction such as "University – IT-companies" can lead to undesired and unexpected consequences, including the loss of significant amount of intellectual and/or material resources, lowering educational-qualification level of specialists, appearing of limitation in education and development of ability to creative thinking [6, 7, 11, 13].

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2 The Statement of Researched Problem

Increase of interaction efficiency can be influenced by decision support systems (DSS) for model-oriented academic-industry interaction, which is developed on the basis of the latest methods, technologies, and approaches of system analysis, forecasting, fuzzy logics, neural networks, artificial intelligence, etc. [2, 5, 20, 21, 24, 32]. Usage of the above mentioned methods when designing modern DSS allows to process the essential amount of different-type information on a new level of intellectual interaction of a decision maker (DM) and computer system [26, 27]. Nowadays there is still an unsolved question of selecting partnership models based on developing the system of multi-criterion assessment of possible level of interaction between universities and IT-companies. Usage of such class DSS in some specific practical cases makes it possible to select the best variant of the model of interaction development such as “University – IT-company” [6, 13, 22, 28, 29].

The aim of this work is development and research DSS based on fuzzy logic to increase the efficiency of multi-criterion decision making processes for model-oriented interaction such as “University – IT-company” in case of changing dimension of input coordinates vector.

Preliminary researches and analysis of successful interaction experience within different-type consortia prove that nowadays solving the task of estimating the level of interaction between universities and IT-companies involves the selection of one of the four formed alternative models [6, 7] as alternative decision variants $E_i, (i = 1\ldots4)$, where decision variant E_1 corresponds with the model A1 (interaction between university and IT-company in the sphere of education and study organization, knowledge sharing, targeted personnel training for IT-industry); variant E_2 – model A2 (organization and support of certification processes of interaction results); variant E_3 – model B (creating collective center of scientific researches, developing collective scientific projects); variant E_4 – model C (creation of student research groups with business orientation and realization of startups). Herein the efficiency of process of selecting interaction model essentially depends on chosen criterion $x_j, (j = 1, 2, \ldots, n)$, which characterizes each partner of the relevant future consortium such as “University – IT-company”. Usage of fuzzy logics and hierarchical structure of input data (coordinates) when developing model-oriented DSS of such type allows to increase efficiency of multi-criterion selection of interaction model between universities and IT-companies, which is achieved by simplifying the process of formation and processing knowledge, taking into account significant amount of quality indicators and selection of optimal solution for a large amount of input expert information [26, 27, 32].

3 Structure and Rule Base Reconfiguration of Fuzzy DSS with Hierarchically-Organized Structure

In this paper there is considered an approach of designing fuzzy hierarchical DSS with the exception of defuzzyfication procedure on each previous hierarchical level and fuzzyfication procedure - on the next relevant hierarchical level. Herein the result of fuzzy logical conclusion of each subsystem of previous level of hierarchy directly (without additional processing) is passed to a block of fuzzy logical conclusion of relevant subsystem of each DSS hierarchy level [26, 27]. Informational technologies which realize DSS of such type, provide support to decision-making with high performance. Herein the quantity and complexity of computing operations significantly are reduced by eliminating intermediate "defuzzyfication-fuzzyfication" procedures between nearest hierarchical levels [14, 16–18, 23].

Let's consider a fuzzy one-level system (Fig. 1) that simulates dependency

$$y = F(x_1, x_2, \ldots, x_9),$$

where x_i, $i = 1, 2, \ldots, 9$ − input linguistic variables; y − output variable.

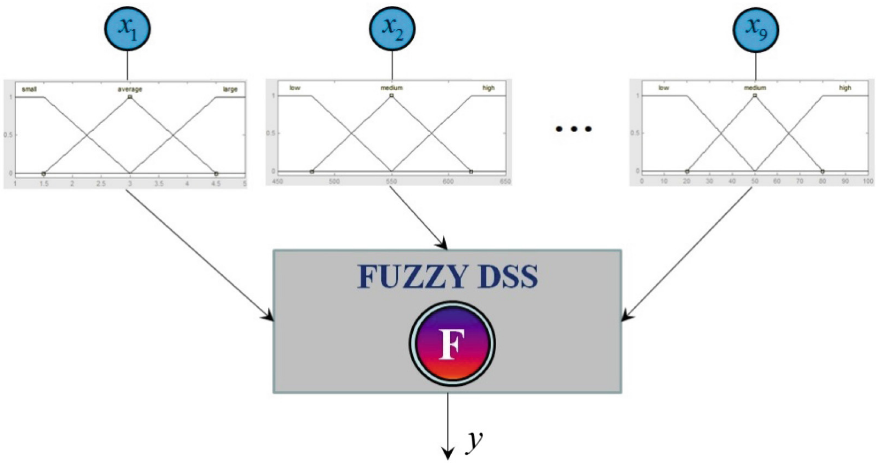


Fig. 1. The structure of one-level fuzzy DSS

Connections between input variables and output value are described with the help of fuzzy rules of one knowledge base f_1.

One of the possible variants of hierarchically-organized structure of fuzzy DSS we will design (Fig. 2) on the basis of decomposition of input coordinates vector $(x_1, x_2, \ldots, x_9)$ by joining them in the next i three-component group combination E_i:

$$E_i = \{\{x_1, x_2, x_3, x_4\}, \{x_5, x_6\}, \{x_7, x_8, x_9\}\}.$$

Herein relevant subsystems of one of the alternative structures of fuzzy DSS (Fig. 2), for example j, realize next functional dependencies

$$St_j = \{y_1, y_2, \ldots, y_4, y\} = \left\{ \begin{array}{l} y_1 = f_1(x_1, x_2, x_3, x_4), y_2 = f_2(x_5, x_6), \\ y_3 = f_3(x_7, x_8, x_9), y_4 = f_4(y_1, y_2), y = f_5(y_3, y_4) \end{array} \right\}.$$

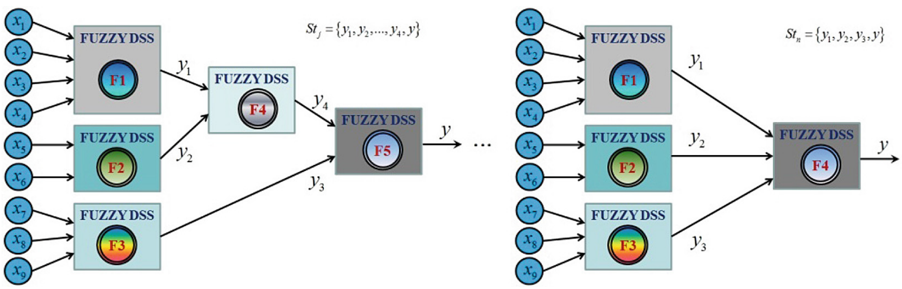


Fig. 2. The alternative hierarchical structures $St_j, \ldots, St_n$ of multi-level fuzzy DSS

The results of investigating [16–18, 26, 27] fuzzy hierarchically-organized systems prove that number of production rules significantly decreases in the process of the fuzzy DSS synthesis based on hierarchical decomposition of input $(x_1, x_2, \ldots, x_9)$ and intermediate (y_1, y_2, y_3, y_4) parameters.

Nowadays there is enough amount of software means to synthesize fuzzy hierarchically-organized DSS, in particular, MATLAB, CubiCalc, FuzzyTECH, etc. [27]. Alternative variants of DSS structures (Fig. 2), which are implemented with exception of intermediate "defuzzyfication-fuzzyfication" procedures between nearest hierarchical levels, allow on the designing stage to optimize the fuzzy DSS by its structural reconfiguration [25].

The main stages of structural reconfiguration procedure are as follows:

1. Synthesis of alternative variants of group combinations of input parameters of fuzzy DSS

$$\bar{E} = \{E_1, E_2, \ldots, E_i, \ldots, E_k\},$$

where k - number of alternative variants of group combinations.
2. Synthesis of alternative variants of structural organization of fuzzy DSS

$$\bar{S}t = \{St_1(E_1), St_2(E_2), \ldots, St_i(E_i), \ldots, St_k(E_k)\}.$$

3. Assessment of each alternative variant of structures $St_i(E_i)$ according to criterion of adequacy $K(St_i), i = \{1, \ldots, k\}$ and indicators of decision making quality.
4. Selection of optimal configuration of hierarchically-organized structure of the fuzzy DSS

$$St_{opt} = Arg\,\underset{i}{Max}\,K(St_i), i \in \{1, \ldots, k\}.$$

In most practical cases reconfiguration of hierarchical structure of the fuzzy DSS according to subparagraphs 1–4 is also appropriate when targets, indicators (criteria) of assessments, preferences system and DM priorities, etc. are changing.

In this study there is considered the developed by authors model-oriented DSS for selecting model $(m = 4)$ of interaction between universities and IT-companies according to preliminary proposed and defined criteria $(n = 27)$. The experience of professionals in the sphere of designing specialized fuzzy system of different purpose shows that with one-level structure of DSS in cases of large dimension of input coordinates vector $X = \{x_j\}, j = 1\ldots n$ sensitivity of their fuzzy rule bases to changes of input coordinates (criterion) values reduces $x_j, (j = 1, 2, \ldots, n)$ [15, 17, 18]. This is primarily due to complexity of creating relevant fuzzy rules to realize all possible dependences between input and output parameters of the system $y_k = f(x_1, x_2, \ldots, x_{27}), k = 1\ldots K$.

There is shown (Fig. 3) the variant of proposed by authors hierarchically-organized DSS St_s to select the best model $E^*, (E^* \in E, E = \{E_1, E_2, E_3, E_4\})$ of interaction between universities and IT-companies, which is created on the basis of input coordinates vector decomposition $X = \{x_j\}, j = 1\ldots 27$ with their association in the next s-group combination:

$$X_s = \left\{ \begin{array}{l} \{x_1, x_2, x_3\}, \{x_4, x_5, x_6, x_7\}, \{x_8, x_9, \ldots, x_{13}\}, \{x_{14}, x_{15}, x_{16}, x_{17}\}, \\ \{x_6, x_{18}, x_{19}\}, \{x_{18}, x_{19}, \ldots, x_{23}\}, \{x_{24}, x_{25}, x_{26}, x_{27}\} \end{array} \right\}.$$

Herein, corresponding subsystems of DSS (Fig. 3), among them $\{FES_1, FES_2, \ldots, FES_{10}, FES_{11}\}$, realize next functional dependencies for s alternative structure $St_s = \{y_1, y_2, \ldots, y_{10}, y\}$ of DSS:

$$St_s = \left\{ \begin{array}{l} y_1 = f_1(x_1, x_2, x_3), y_2 = f_2(x_4, x_5, x_6, x_7), y_3 = f_3(x_8, x_9, \ldots, x_{13}), \\ y_4 = f_4(x_{14}, x_{15}, x_{16}, x_{17}), y_5 = f_5(x_6, x_{18}, x_{19}), y_6 = f_6(x_{18}, x_{19}, \ldots, x_{23}), \\ y_7 = f_7(x_{24}, x_{25}, x_{26}, x_{27}), y_8 = f_8(y_1, y_2), y_9 = f_9(y_3, y_4), \\ y_{10} = f_{10}(y_5, y_6), y = f_{11}(y_7, y_8, y_9, y_{10}) \end{array} \right\}.$$

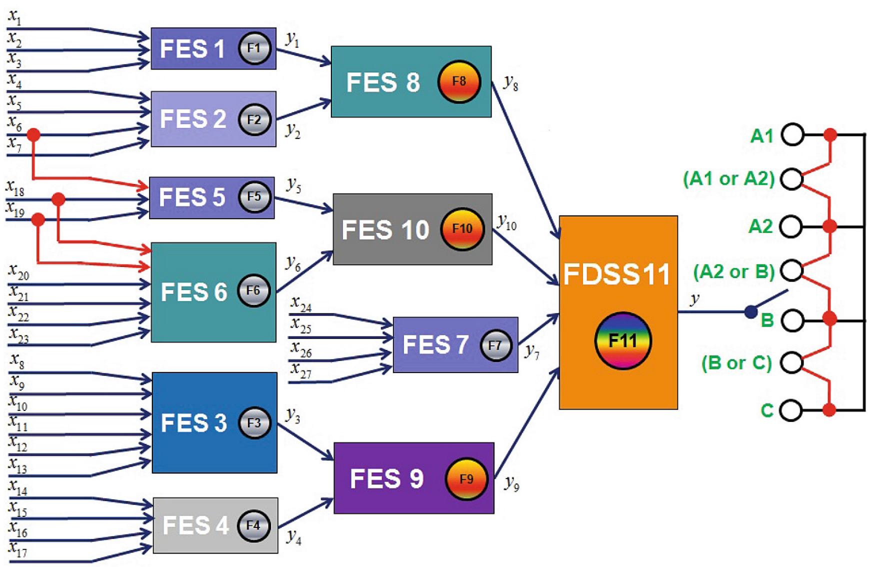


Fig. 3. The structure of knowledge-based fuzzy DSS for selecting model of interaction within consortia “University – IT-company”

So, for example, the fourth subsystem $y_4 = f_4(x_{14}, x_{15}, x_{16}, x_{17})$ for assessment of level of business orientation of department in relevant university is being created (Fig. 3) on the basis of four input coordinates (x_{14} – IT-certification of department teachers, x_{15} – number of business courses, x_{16} – experience in organizing student companies, x_{17} – experience in organizing mixed creative teams for execution and realization of IT-projects), which are combined according to common abilities, and one output coordinate (y_4 – level of business orientation of university department) with realization of relevant knowledge base, which includes 81 fuzzy rules of production type (Table 1). To design fuzzy rule bases for developed structure of DSS (Fig. 3) there are used linguistic terms $\{L, M, H\}$ for input coordinates, $\{L, LM, M, MH, H\}$ for intermediate and output coordinates with triangular shape of membership function [26, 27, 31, 32].

Table 1. Selective rule-set of knowledge base of the fourth subsystem

Number of rule	2	3	4		43	44	45	46		77	78	79
x_{14}	L	L	L	…	M	M	M	M	…	H	H	H
x_{15}	L	L	L	…	M	M	M	H	…	H	H	H
x_{16}	L	L	M		H	H	H	L		M	M	H
x_{17}	M	H	L	…	L	M	H	L	…	M	H	L
y_4	L	LM	L		M	M	MH	M		MH	H	MH

In the process of decision making using the fuzzy hierarchically-organized DSS with variable structure of input coordinates vector there appears a need to develop effective approaches to the reduction (reconfiguration) of rule bases of fuzzy models [16–18]. The necessity of relevant reconfiguration including input coordinates, which are at the option of DM excluded from the vector of input coordinates, appears in case of interaction between DM and DSS in interactive modes. In such modes DM can reduce the dimension of DSS vector of input coordinates, excluding from the further consideration those coordinates, the values of which DM does not know or cannot get accurately [27]. For example, synthesized DSS operates effectively with 15 input coordinates ($N = 15$), but in some cases DM can accurately estimate only 11 input signals ($N_E = 11$) and other 4 input signals ($N_{NE} = 4$) DM excludes from consideration, as they are not evaluated, $N_E + N_{NE} = N$. Herein the dimension of input coordinates vector X is reduced from 15 to 11. In the process of the fuzzy DSS operation with the fixed structure of knowledge bases and under variable structure of input data vector ($N_E < N$) the results of decision making y get deformed. This is due to the fact that meaning of input coordinates ($N_{NE} = 4$), which do not take part in designing fuzzy DSS and are equal to zero, through corresponding fuzzy rules influence negatively on the result y [17, 18].

One of the approaches to reconfiguration of DSS with relevant reduction of rule bases with variable structure of input coordinates vector is the approach that consists in identification of minor model parameters [26]. Herein the number of rules essentially decreases, that allows increasing sensitivity of the system to changes of input coordinates vector's values. There are also methods of assessing the importance of input indicators, among which there are: trial and error method, method of fuzzy average curves, and method of expert ranking [27]. Herein the relevant methods are dependent enough from dimension of the vector of input coordinates. When the number of system inputs increases the complexity of their assessment increases too. Using the known method of weighting coefficients of fuzzy rules there is a necessity in their additional configuration at every structural reconfiguration of input data [26].

Limited features of the considered approaches and methods of DSS reconfiguration with relevant reduction of rule bases do not allow using them directly for optimization of the fuzzy hierarchical DSS with variable structure of vector of input data.

With the implementation of the first stage (Fig. 4) antecedents of all 81 rules of the fourth subsystem $y_4 = f_4(x_{14}, x_{15}, x_{16}, x_{17})$ are processed. Herein singular signal is sent to informational inputs of keys Key 1,…,Key 4. If, for example, two input signals $x_{16} = NE$ and $x_{17} = NE$ are not interesting for DM or they cannot be evaluated, then Key 1 and Key 2 are locked, and to the control inputs of Key 5, Key 6 and integrator $\sum 1$ there come relevant singular signals. Herein Key 5 and Key 6 are locked, that provides reduction of rules antecedents (Fig. 4) by means of automatic exclusion of all components with input coordinates x_{16}, x_{17} as Key 7 and Key 8 stay unlocked.

Modified antecedents contain only input coordinates x_{14} and x_{15}, as to informational inputs of Key 5 and Key 6 from rule base comes information about quantitative characteristics $\{L = 1, M = 2, H = 3\}$ of relevant LT of activated rules of the fourth DSS subsystem. Herein reduced rule base for realization of modified dependency $y_4 = f_4(x_{14}, x_{15})$ is reduced from 81 to 9 rules [17, 26].

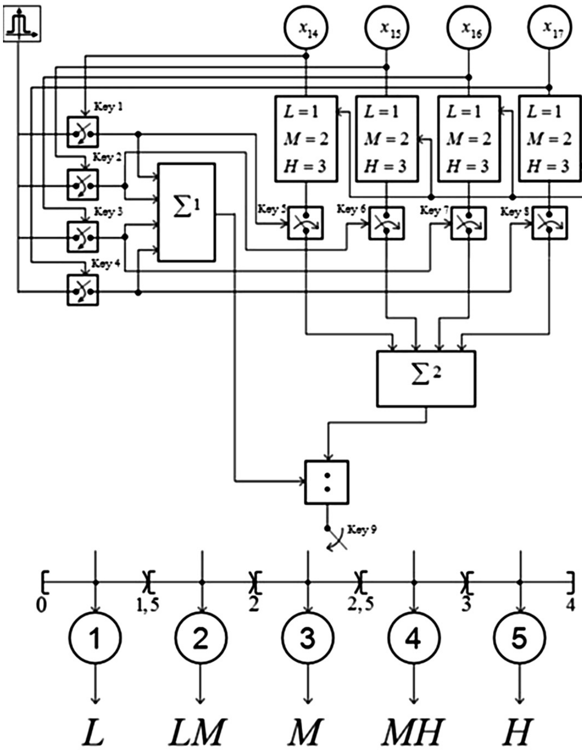
With the implementation of the second stage (Fig. 4) correction of consequents of components y_i of output coordinate y_4 is done according to reduced rule base, that is automatically designed after realization of the first stage (numerical values $\{L = 1, M = 2, H = 3\}$ of relevant LT of reduced rules come to inputs of integrator $\sum 2$, Fig. 4).

To illustrate in details the method of two-stage reconfiguration of fuzzy DSS rule bases let's consider, for example, fuzzy rule № 37 (Fig. 4):

$$\text{IF } x_{14} = M \text{ AND } x_{15} = M \text{ AND } x_{16} = L \text{ AND } x_{17} = L \text{ THEN } y_4 = LM. \quad (1)$$

In the process of the first stage reconfiguration the antecedent of this rule (1) automatically is adjusted and newly formed antecedent is transformed to the form:

$$\text{IF } x_{14} = M \text{ AND } x_{15} = M. \quad (2)$$



№	x_{14}	x_{15}	x_{16}	x_{17}	y_4
1	L	L	L	L	L
3	L	L	L	H	LM
5	L	L	M	M	LM
9	L	L	H	H	M
10	L	M	L	L	L
11	L	M	L	M	LM
14	L	M	M	M	M
18	L	M	H	H	MH
19	L	H	L	L	LM
21	L	H	L	H	M
22	L	H	M	L	LM
28	M	L	L	L	L
31	M	L	M	L	LM
33	M	L	M	H	M
37	M	M	L	L	LM
39	M	M	L	H	M
42	M	M	M	H	MH
43	M	M	H	L	M
46	M	H	L	L	M
51	M	H	M	H	MH
52	M	H	H	L	M
54	M	H	H	H	H
55	H	L	L	L	LM
57	H	L	L	H	M
58	H	L	M	L	LM
60	H	L	M	H	M
63	H	L	H	H	MH
65	H	M	L	M	M
69	H	M	M	H	MH
71	H	M	H	M	MH
72	H	M	H	H	H
73	H	H	L	L	M
75	H	H	L	H	MH
77	H	H	M	M	MH
79	H	H	H	L	MH
81	H	H	H	H	H

Fig. 4. Mechanism of two-stage reconfiguration of the rule base in fourth subsystem $y_4 = f_4(x_{14}, x_{15}, x_{16}, x_{17})$

With implementation of the second stage reconfiguration by calculating ratio $U_{out}(\sum 2)/U_{out}(\sum 1)$of output signals of integrators $\sum 1$ and $\sum 2$ there is formed an assessment:

$$\text{Result} \in \{[0, 1.5), [1.5, 2), [2, 2.5), [2.5, 3), [3, 4]\}. \quad (3)$$

Depending on the size of signal Result (3) the form of consequent with the help of Key 9 is transformed to the one of relevant linguistic terms $\text{LT}_{\text{Result}} = \{L, LM, M, HM, H\}$ (Fig. 4). For the rule № 37 the signal Result = 2 and respectively (Fig. 4) Result $\in [2, 2.5)$, that provides automatic correction of consequent and modified rule № 37 takes its final form (4):

$$\text{IF } x_{14} = M \text{ AND } x_{15} = M \text{ THEN } y_4 = M. \quad (4)$$

Characteristic surfaces of the fourth subsystem $y_4 = f_4(x_{14}, x_{15}, x_{16}, x_{17})$ are shown on the Fig. 5.

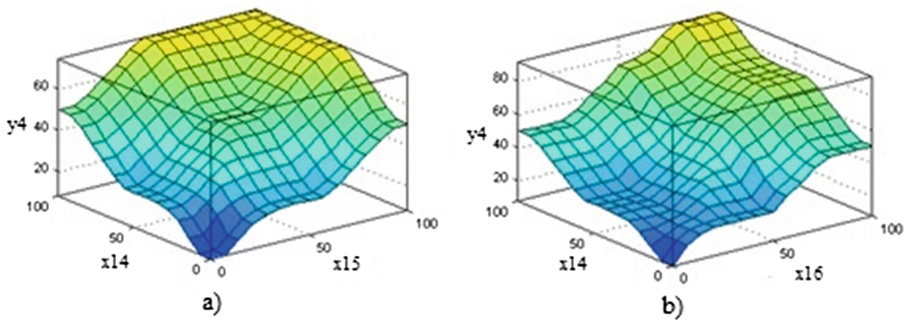


Fig. 5. Characteristic surfaces of the fourth subsystem: (a) $y_4 = f_4(x_{14}, x_{15}); x_{16}, x_{17} - const$; (b) $y_4 = f_4(x_{14}, x_{16}); x_{15}, x_{17} - const$

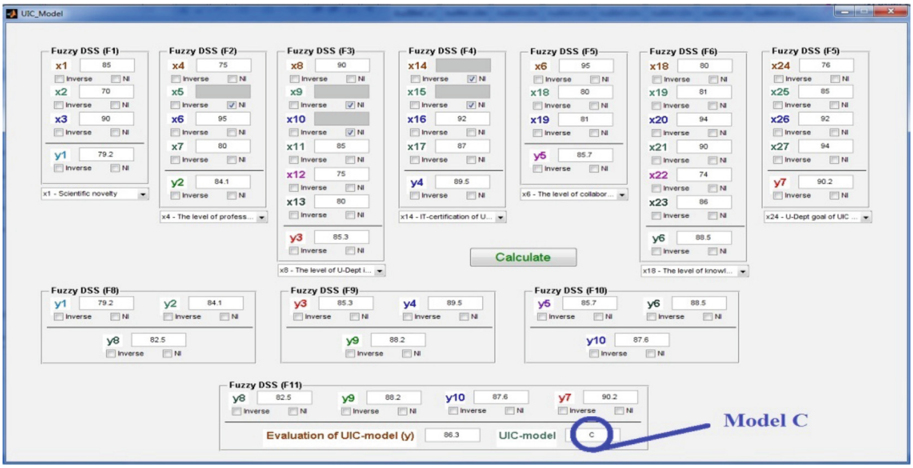


Fig. 6. The interface of developed knowledge-based DSS for selecting the model of academic-industry interaction for consortia "University – IT-company"

Human-computer interface, program realization and results of DSS work for selecting the model of interaction within consortia such as "University – IT-company" are shown on Fig. 6 ($x_5, x_9, x_{10}, x_{14}, x_{15}$ are not interesting).

For the presented on Fig. 6 set of input data $X = \{x_j\}$, $j = 1\ldots27$ developed DSS on fuzzy logic (Fig. 3) creates on its output consolidated signal, which recommends corresponding future partners for interaction (specific University and specific IT-company) to choose as optimal model E^* the model of interaction C: $E^* = C, (E^* \in E$, $E = \{E_1 = A1, A2, B, C\})$. As input data for modular DSS different-type input variables $X = \{x_j\}$, $j = 1\ldots27$ are used, which characterize performance indicators of university (of relevant IT-department) and IT-companies, which are part of academic-industrial interaction. Some of input data are quantitative, and some – qualitative. Quantitative input indicators can be created on the basis of results of statistical information processing, and qualitative – on the basis of results of expert evaluations (using individual and group assessments) [3, 4, 15, 20].

4 Conclusions

In this paper there are shown results of developing hierarchically-organized DSS, which is synthesized on the basis of using fuzzy logic, to increase efficiency of decision-making processes for selecting optimal model E^* of partner interaction under consortia such as "University – IT-company". Made by authors analysis of samples of successful innovative interaction of academic institutions and IT-companies [7, 9–11, 13] proves that creation of different groups, consortia, associations and alliances such as "University – IT-company" to solve current and future problems in higher education sphere based on mutual working experience in computer science area and internet-communications is a perspective direction in the area of improving efficiency of higher education system. In particular, the National Aerocosmic University "Kharkiv Aviation Institute" named after M. E. Zhukovskiy, Odessa National Polytechnic University, Yuriy Fedkovych Chernivtsi National University, Chernihiv State University, Petro Mohyla Black Sea National University, Institute of Cybernetics of National Academy of Sciences of Ukraine and others are members of such international academic-industrial consortia, which includes universities and IT-companies from Great Britain, Spain, Italy, Portugal, Ukraine and Sweden [6, 7, 19, 30]. This consortium is created to develop and implement models of interaction between universities and industry (IT-companies) such as A1, A2, B and C within the project TEMPUS- CABRIOLET 544497-TEMPUS-1-2013-1-UK-TEMPUS-JPHES "Model-oriented approach and Intelligent Knowledge–Based System for Evolvable Academia-Industry Cooperation in Electronics and Computer Engineering" (2013–2016).

Approbation of the developed model-oriented DSS proves its high efficiency, that is confirmed by authors as in solving practical tasks of selecting a model of interaction within consortia such as "University – IT-company", and in solving different-type tasks of transport logistics [8, 12, 14, 16, 18] in particular when selecting the best transport company from the set of existing alternative variants, etc.

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