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Intelligent Assistance of Decision-Making in the Management of Multifactor Systems Based on Fuzzy Cognitive Models

Baryi Ilyasov
Department of Technical Cybernetics
Ufa State Aviation Technical University
Ufa, Russian Federation
ilyasov@tc.ugatu.ac.ru

Elena Makarova
Department of Technical Cybernetics
Ufa State Aviation Technical University
Ufa, Russian Federation
ea-makarova@mail.ru

Elena Zakieva
Department of Technical Cybernetics
Ufa State Aviation Technical University
Ufa, Russian Federation
zakievae@mail.ru

Elvira Gabdullina
Department of Technical Cybernetics
Ufa State Aviation Technical University
Ufa, Russian Federation
gabdullina_er@mail.ru

***Abstract*—The article deals with the development of fuzzy cognitive models of the processes of analysis and management of the quality of education as a multifactor system. The approach based on definition of trajectories of achievement of target indicators of education quality with the use of technologies of knowledge engineering is offered. The functional scheme of the model of education quality management is developed. The structuring of factors influencing the quality of education is carried out: management and target indicators, as well as indicators characterizing the current state of the education system are identified. Cognitive modeling is carried out to analyze and support of making decisions on education quality management. Fuzzy cognitive map (FCM) is developed on the basis of statistical data using methods of statistical and intelligent analysis. The analysis of the integrated system indicators of the constructed FCM, the results of which identified the most significant concepts that have the greatest impact on the state of the education system is carried out. The algorithm of Silov is applied for searching for the ways of direct and indirect influence of concepts on each other through the matrix of interaction between concepts, representing intelligent cognitive agent; the search procedure is based on the use maxtriangular operation with fuzzy matrices using the T - and S-norms. The maximum positive and negative ways between the management and target concepts of the FCM are formed, which are considered as possible scenarios for the use of budgetary funds to improve the quality of education. The constructed ways represent a chain of fuzzy rules of the form "if-then" and can be the basis for the formation of recommendations for decision-making in the management of the quality of education.**

Keywords—fuzzy cognitive maps, quality of education, control scheme, intelligent algorithms, trajectories, decision - making

I. INTRODUCTION

To improve the quality of education as a priority direction of the state policy of the Russian Federation, the state Program of the Russian Federation "Development of education" for 2013-2020 [1] defines the target indicators and the amount of financial resources for the implementation of social policy. The management of the Program implementation assumes monitoring [2] of achievement of target indicators of education quality of subjects of the Federation. It should be noted that the problem of education quality management as a complex system is associated with a variety of management goals: improving the quality of pre-school, of supplementary, school and vocational education, providing the education system with personnel, financial support, updating the infrastructure of the education system, effective youth policy, etc. At the same time, a high degree of uncertainty in the economic processes taking place in the system, the changing requirements of the labor market and social changes can negatively affect the level of achievement of the target indicators [3-5], which affects the satisfaction of the population with the quality of educational services, the effectiveness of the use of budget funds aimed at education, the provision of the needs of the economy with highly qualified personnel in priority areas, etc. One of the approaches to improving the efficiency of management is an approach based on determining the trajectories of achieving the target indicators of the quality of education using the technologies of knowledge engineering. The article proposes a procedure for the implementation of this approach, including the construction of a model of education quality management system, the construction of a fuzzy cognitive map for the analysis of the quality of education based on intelligent data analyses technologies, the analysis of fuzzy cognitive map of the FCM based on the algorithm of V.B. Silov and the construction of trajectories of the influence of control actions on the target indicators of the quality of education as a multifactor system.

II. SCHEME OF THE MODEL OF EDUCATION QUALITY MANAGEMENT SYSTEM

As part of the research, a functional scheme (Fig. 1) of the model of education quality management system, which is a two-level, was developed.

The lower level of education quality management is implemented in the form of a closed loop and is aimed at achieving the target coordinates of the educational system $Y^0 = \{Y_i^0\}$ The target indicators of the quality of education include: Y_1^0 – "The proportion of employed graduates of educational organizations under the bachelor's program"; Y_2^0 – "The proportion of employed graduates of educational organizations under the program of higher education-specialty, master's degree";Y_3^0 – "The proportion of employed graduates of educational organizations under the program of secondary vocational education (training of skilled workers, employees)"; Y_4^0 – "The proportion of employed graduates of educational organizations under the program of secondary vocational education (training of middle-level specialists); Y_5^0 – "The proportion of the number of employed population aged 25-65 years who have undergone advanced training and (or) vocational training"; Y_6^0 – "The proportion of the higher education sector in domestic research and development costs".

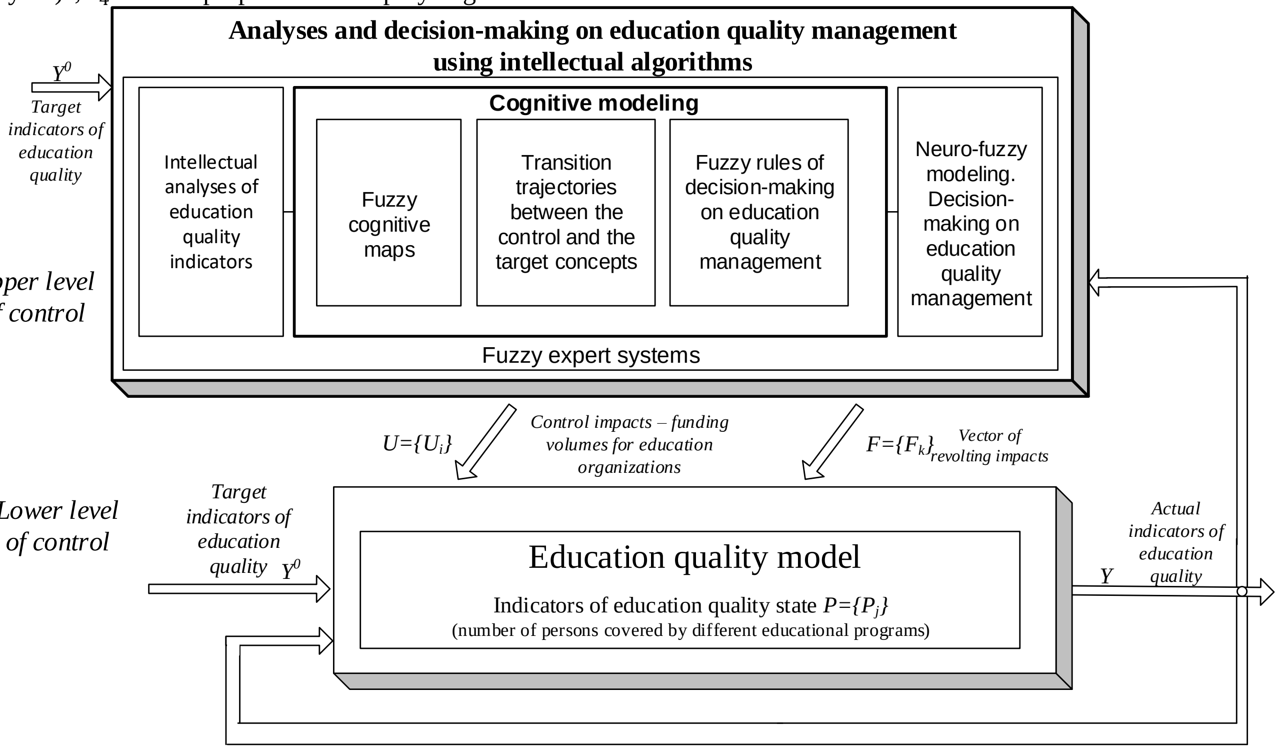

Fig. 1. The functional scheme of the model of education quality management

The indicators $P = \{P_i\}$ characterize the quality of education for general, secondary vocational, higher education, graduate school, as well as for additional education of children and adults. These indicators are measured objectively and are internal (intermediate) parameters of the education quality model. The indicators describe the population coverage with different educational programs: P_1 – "Coverage of children with primary General, basic General and secondary General education (7-17 years)"; P_2 – "Coverage of young people with educational programs of secondary vocational education-training programs for skilled workers, employees (15-17 years)"; P_3 – "Coverage of young people with educational programs of secondary vocational education-training programs for middle managers (15-19 years)"; P_4 – "Coverage of young people with educational programs of higher education (17-25 years); P_5 – "Number of graduate students per 100 students"; P_6 – "Coverage of children aged 5 to 18 years with additional education programs"; P_7 – "The number of persons trained in the organization for additional professional programs for 10,000 people of the population"; P_8 – "The number of persons trained in the organization for qualification programs for 10,000 people of the population"; P_9 – "The number of persons trained in organizations for retraining programs for 10,000 people of the population".

The education system operates under conditions of uncertainty of the external environment, characterized by disturbances $F = \{F_i\}$ in the form of changes in labor market factors, socio-economic conditions, etc.

The upper level of management is built to analyze the results of the functioning of the education system and decision-making aimed at improving the quality of education by adjusting the distribution of financial resources of educational institutions of the main stages of education (General, secondary professional, higher). Control actions are allocated: U_1 – "Total funding of all educational institutions implementing General education programs, thousand rubles/person"; U_2 – "funding of educational institutions of higher education, thousand rubles/person"; U_3 – "the Amount of funds received in secondary vocational education, thousand rubles/person." The implementation of the upper level of management is based on intelligent algorithms using intelligent data analyses methods, cognitive and neuro-fuzzy modeling.

III. COGNITIVE MODELING PROCEDURE

To model, predict and support decision-making on education quality management as a complex semi-structured, poorly formalized system, a universal tool for understanding the behavior of complex systems is used - the apparatus of cognitive maps (CM). The use of CM is due to the possibility of visual representation of the system in the form of interrelated concepts, the ability to interpret the cause-effect relationships between concepts and the construction of trajectories from the initial (control) concepts and achieve the target concepts through the intermediate [6].

The construction of cognitive maps is carried out on the basis of statistical data on the results of the survey of the quality of education in the regions of the Russian Federation, provided by the Federal state statistics service [7] and the Unified interdepartmental information and statistical system for the regions of the Russian Federation [8] for 2015/2016. In order to determine the number of significant features in the source data, intelligent data analysis is carried out using factor analysis or the principal components method, the result of which is a finally formed set of cognitive map concepts. Taking into account the results of the structuring of education quality indicators [9-10], management, intermediate and target concepts of CM are formed.

Next, the search for cause-and-effect relationships between concepts based on correlation and regression analysis is carried out; a cognitive map is constructed (Fig. 2) and its expert assessment is carried out. The directions of the links on the CM were determined on the basis of regression analysis, and the values of the weighting coefficients of the links were established using correlation analysis [11]. The influence of the target concepts on the control concepts is indicated in the figure by dashed lines.

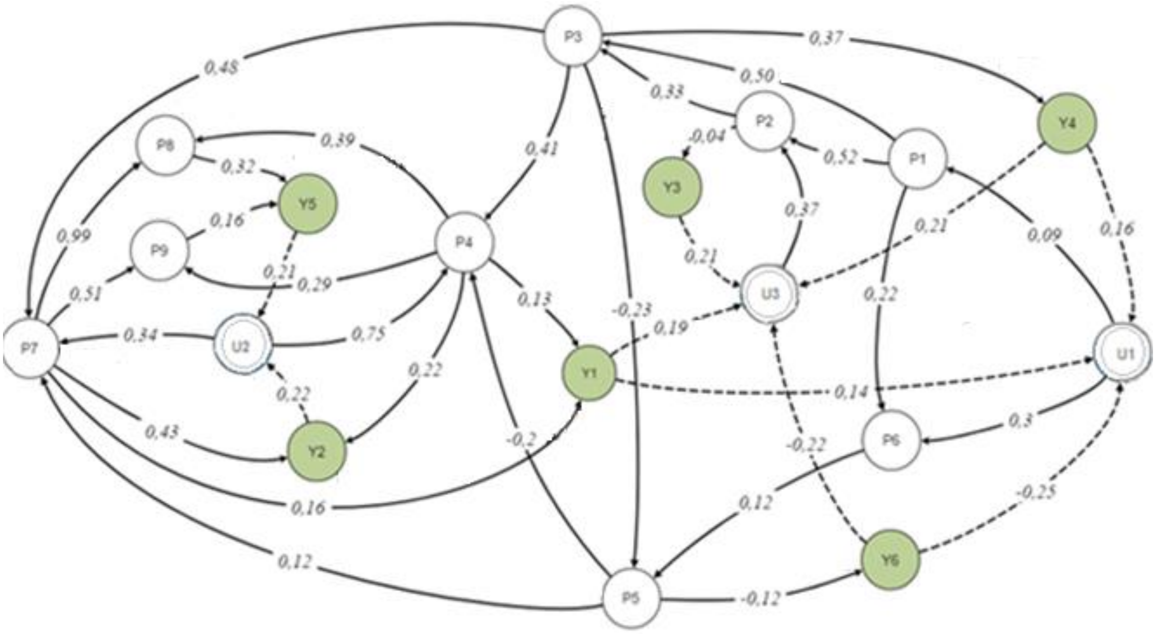

Fig. 2. Fuzzy cognitive map for the analysis of the quality of education

In mathematical form, the FCM is represented as an adjacency matrix $W=[w_{ij}]_{n\times n}$, the elements of which represent the degree of influence of the concept *i* on the concept *j* in the range of real numbers [-1,1], taking into account the direction of influence.

Since the directed edges of the graph of the constructed cognitive map reflect not only cause-effect relations between concepts, but also allow to distinguish the intensity of interaction between them in the range of real numbers [-1,1], it becomes possible to use the apparatus of fuzzy cognitive modeling. For the first time proposed by B. Kosko [12], fuzzy cognitive maps (FCM) were further subjected to various modifications to simulate complex systems.

In this work, we use the FCM of V.B. Silov [13], in which the relations between the concepts are considered as elements of the fuzzy adjacency matrix for the FCM graph; and the problem of processing negative influences is solved by doubling the power of the set of concepts and their separate processing. The Figure 3 presents the scheme of algorithm of carrying-out of the analysis of a fuzzy cognitive model developed by V.B. Silov.

For the solution of problems of cognitive modeling [14] we introduced a causal algebra, which is based on maxtriangular operations with fuzzy matrices, when the fuzzy output values of concepts are calculated using a characteristic of the fuzzy logic operations of *T* - and *S*-norms on the fuzzy input values of concepts and weights of influence.

The FCM of Silov represent a network $G=(K, W)$, where *K* is a set of concepts; *W* is a set of connections, and the elements of the fuzzy relation $w_{ij}=W(Ki, Kj)\in[-1,1]$ characterize the direction and intensity (weight) degree of the influence between the concepts K_i and K_j. In the static analysis of cognitive maps of Silov, the search for the final (cumulative) interaction of concepts with each other, taking into account direct and indirect influence is carried out, and a matrix of mutual influence is built.

According to the scheme of the algorithm for the analysis of the FCM of education quality at the first step, a square matrix of adjacency *W* is formed, presented in Table 1. The dimension of the matrix is determined by the total number of concepts (n=18); the elements of the matrix represent the degree of influence of the concept-cause located in the row on the concept-consequence in the column.

In the next step, on the basis of the adjacency matrix *W* a "double matrix" of positive links $R=[r_{kq}]_{2n\times 2n}$ is formed. The need to construct the matrix *R* is due to the requirements of fuzzy algebra methods – the introduction of fuzziness in the range of real numbers [0, 1] and associated with the exclusion of negative elements. Each element of the "double" matrix is defined as follows: if the corresponding element of the adjacency matrix is $w_{ij}>0$, then $r_{2i-1,2j-1}=w_{ij}$, $r_{2i,2j}=w_{ij}$; if $w_{ij}<0$, then $r_{2i-1,2j}= -w_{ij}$, $r_{2i,2j-1}=-w_{ij}$, in other cases the elements of the matrix R are zero.

The Table 2 presents a fragment of the "double matrix" R, describing the influence of the intermediate concepts of the FCM of education quality P_2, P_3, P_4, P_5 on each other; the elements of the adjacency matrix W are split in R into two rows as follows: positive elements are written on the main diagonal, for example P_2 – P_3, P_2' – P_3', and negative elements are written on the side diagonal, for example, P_3 – P_5', P_3' – P_5.

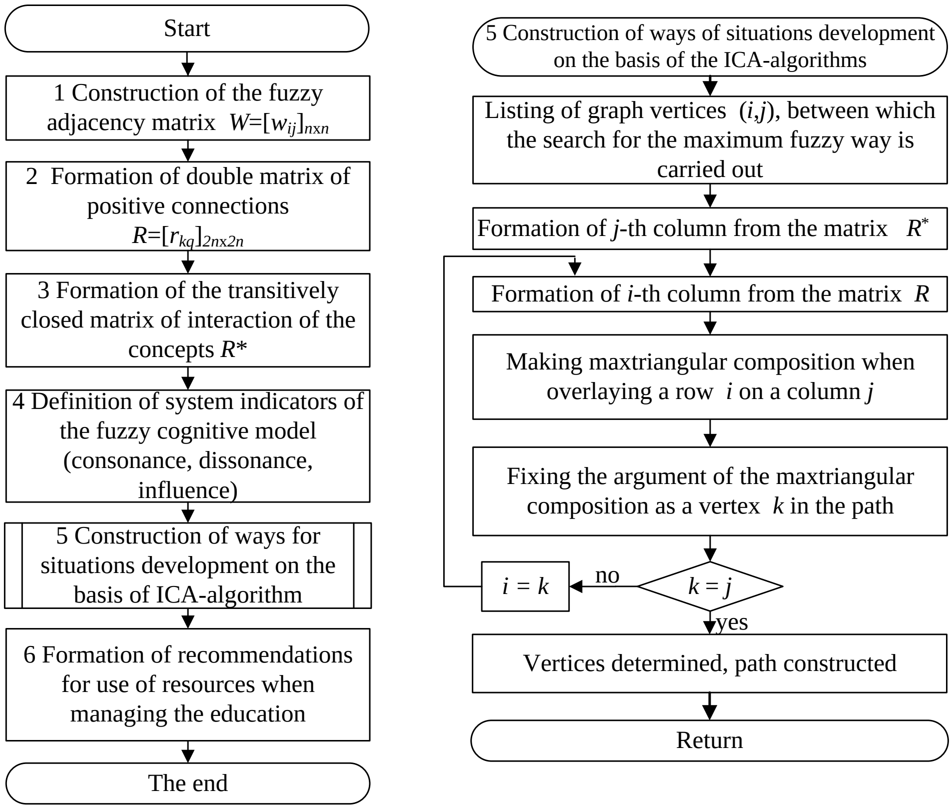

Fig. 3. The scheme of the fuzzy cognitive map analysis algorithm

TABLE I. ADJACENCY MATRIX W

W	***U₁***	***U₂***	***U₃***	***P₁***	***P₂***	***P₃***	***P₄***	***P₅***	***P₆***	***P₇***	***P₈***	***P₉***	***Y₁***	***Y₂***	***Y₃***	***Y₄***	***Y₅***	***Y₆***
U_1				0.09					0.3									
U_2							0.75			0.34								
U_3					0.37													
P_1					0.52	0.5			0.22				0.42	0.57	0.29	0.42	0.31	
P_2						0.33							0.27		0.04	0.26	0.19	
P_3							0.41	-0.23		0.48			0.34	0.55	0.31	0.37		
P_4											0.39	0.29	0.13	0.22	0.19	0.18	0.18	
P_5							-0.2			0.12								-0.12
P_6								0.12					0.24	0.29				
P_7											0.99	0.51	0.16	0.43	0.26	0.35		
P_8																	0.32	
P_9																	0.16	
Y_1	0.14	0	0.19															
Y_2	0.17	0.22	0.23															
Y_3		0.2	0.21															
Y_4	0.16	0.2	0.21															
Y_5		0.21																
Y_6	-0.25		-0.22															

TABLE III. A FRAGMENT OF A DOUBLE MATRIX R

R	P_2	P_2’	P_3	P_3’	P_4	P_4’	P_5	P_5’
P_2	0	0	0.33	0	0	0	0	0
P_2’	0	0	0	0.33	0	0	0	0
P_3	0	0	0	0	0.41	0	0	0.23
P_3’	0	0	0	0	0	0.41	0.23	0
P_4	0	0	0	0	0	0	0	0
P_4’	0	0	0	0	0	0	0	0
P_5	0	0	0	0	0	0.2	0	0
P_5’	0	0	0	0	0.2	0	0	0

To determine the indirect influence of all the concepts of the FCM of the quality of education on each other, a transitive-closed matrix of mutual influences of concepts is constructed, consisting of positive-negative pairs of elements characterizing the maximum positive and negative cause-and-effect paths between all concepts. The matrix of mutual influences R^* is formed by a special rule of transformation: $(v_{ij}, \overline{v_{ij}})$: $v_{ij} = max(r_{2i-1,2j-1}, r_{2i,2j})$, $\overline{v_{ij}} = -max(r_{2i-1,2j}, r_{2i,2j-1})$. The constructed matrix of mutual influences R^* allows to define the coordinated relations of mutual influence of all concepts of FCM of quality of education that can be used for the analysis of dynamics of achievement of the set purposes of education quality. It should be noted that the implementation of the transitive closure procedure requires the introduction of control feedbacks in the FCM, shown in Figure 2 by dashed lines.

A fragment of the received closed matrix of interactions R^* is presented in Table 3, which shows that, for example, with the growth of funding for General education U_2, the target quality of education Y_5 is slightly increased – the proportion of the employed population aged 25-65 years who have undergone advanced training and (or) vocational training, etc. Further analysis of the matrix R^* showed that the changes in the investments of budgetary funds of educational organizations implementing programs of General education U_1 and secondary vocational education U_3 do not have a significant impact on the target concepts, and the growth of investments U_2 has a small impact on the target concepts: the proportions of the employed bachelor graduates of Y_1, specialist's degrees and master degrees of Y_2, and the employed population, held qualification training and professional training Y_5.

TABLE IV. A FRAGMENT OF A CLOSED MATRIX OF INTERACTIONS R^*

R^*	Y_4		Y_5		Y_6	
U_1	0.01665	-0.00003	0.01349	-0.00123	0.00124	-0.00432
U_2	0.00166	0.00000	0.26386	-0.00005	0.00012	-0.00009
U_3	0.04518	-0.00005	0.03192	-0.00134	0.00337	-0.00003
P_1	0.18500	-0.00019	0.13071	-0.00640	0.01380	-0.00317
P_2	0.12210	-0.00013	0.08627	-0.00363	0.00911	-0.00008
P_3	0.37000	-0.00039	0.26142	-0.01100	0.02760	-0.00026
P_4	0.00142	0.00000	0.17120	-0.00004	0.00011	-0.00008

The constructed matrix of interaction can be used to calculate the system indicators of the FCM [14]: the integral indicators of consonance (dissonance) of the education system influence on the concept, consonance (dissonance) of the concept influence on the system, as well as the indicators normalized to the sum of the whole consonance (dissonance) of the system (Table 4).

TABLE V. FCM SYSTEM INDICATORS

The name of the concepts	**The consonance of influence of the system on the concept**	**The dissonance of the influence system on the concept**	**The consonance of the influence of the concept on system**	**The dissonance of the influence of the concept on system**	**The influence of the system on the concept**	**The influence of the concept on system**
U_1	0.90	0.10	0.83	0.17	0.02	0.04
U_2	0.85	0.15	0.90	0.10	0.05	0.17
U_3	0.92	0.08	0.92	0.08	0.04	0.05
P_1	0.92	0.08	0.89	0.11	0.01	0.15
P_2	0.95	0.05	0.91	0.09	0.06	0.08
P_3	0.96	0.04	0.90	0.10	0.06	0.17
P_4	0.92	0.08	0.90	0.10	0.10	0.08
P_5	0.42	0.58	0.52	0.48	-0.02	0.01
P_6	0.93	0.07	0.58	0.42	0.03	0.01
P_7	0.94	0.06	0.90	0.10	0.09	0.15
P_8	0.87	0.13	0.90	0.10	0.21	0.03
P_9	0.85	0.15	0.90	0.10	0.12	0.02
Y_1	0.86	0.14	0.86	0.14	0.04	0.03
Y_2	0.85	0.15	0.90	0.10	0.10	0.05
Y_3	0.95	0.05	0.93	0.07	0.00	0.02
Y_4	0.97	0.03	0.86	0.14	0.04	0.04
Y_5	0.86	0.14	0.90	0.10	0.11	0.05
Y_6	0.47	0.53	0.84	0.16	0.00	-0.05

The analysis of integral system indicators of the constructed cognitive map revealed a high level of consonance (a measure of confidence in the sign and the force of influence). The high values of the influence of the concepts U_2 (0,17) and P_3 (0,17) on the system indicate that the amount of funding of higher education institutions and the coverage of youth educational programs of secondary vocational education – training programs for middle managers (15-19 years) have a significant impact on the quality of education [15-16]. Further analysis revealed the concepts of P_5 (-0.02) and P_6 (0.03), which have little impact on the quality of education – these are the concepts that characterize the number of graduate students and the coverage of children with additional education; which indicates the small values of these concepts [17].

In addition to the system indicators on the basis of positive-negative transitively closed matrix, it is possible to determine the most positive and negative trajectories. To solve this problem, we use an algorithm that performs the function of an intelligent cognitive agent (ICA-algorithm) and allows the analyst to determine the trajectory of the transition through the concepts. The paths between the concepts identified by the algorithm are considered as possible scenarios for the use of budgetary funds to improve the quality of education and can serve as a basis for the formation of recommendations for decision-making in management [18-23].

According to the ICA-algorithm, to determine the maximum positive and negative path between concepts, it is necessary to select (list) the vertex numbers between the concepts from the constructed matrix of mutual influences R^*, for which it is required to find the maximum fuzzy path "by weight" . To do this, the j-th column y is fixed in the matrix R^*, and the i-th row s is fixed in the matrix R. After that, the value of the argument of the maxtriangular composition of the vector-row s and the vector-column of the fuzzy matrix R^* and R is fixed as a vertex k in the path. It should be noted that the maxtriangular operations with fuzzy matrices assume that the fuzzy output values of concepts are calculated using the characteristic fuzzy logic operations of T - and S-norms on the fuzzy values of the input concepts (e.g., using rules *max–product*). The process of searching by the ICA-algorithm continues until the fixed vertex k coincides with the j-th vertex. Figure 4 shows a fragment of the procedure for extracting vertex numbers of paths using the ICA-algorithm.

Rmax		p1		p2		p3	
		1	2	3	4	5	6
U1	1	0,0900	0,0000	0,0468	0,0002	0,0450	0,0001
	2	0,0000	0,0900	0,0002	0,0468	0,0001	0,0450
U2	3	0,0019	0,0000	0,0107	0,0000	0,0045	0,0000
	4	0,0000	0,0019	0,0000	0,0107	0,0000	0,0045
U3	5	0,0007	0,0001	0,3700	0,0003	0,1221	0,0001
	6	0,0001	0,0007	0,0003	0,3700	0,0001	0,1221

R		p1		p2		p3	
		1	2	3	4	5	6
U1	1	0,09	0	0	0	0	0
	2	0	0,09	0	0	0	0
U2	3	0	0	0	0	0	0
	4	0	0	0	0	0	0
U3	5	0	0	0,37	0	0	0
	6	0	0	0	0,37	0	0

Fig. 4. Fragment extraction procedures of vertices in the ICA-algorithm

The ICA-algorithm allows to construct the paths of development of a situation when setting the operating influences necessary for improvement of quality of education. As an example, let's consider the maximum positive and negative paths between the concepts of U_2 – "The amount of funding for educational institutions of higher education, thousand rubles/person" on the concept of Y_2 – "The Proportion of employed graduates of educational organizations in the program of higher education – specialist's degree, master's degree"; on the matrix of mutual influence of the relationship between the concepts of U_2 and Y_2 correspond to the values (0,165; -0,00003). The positive influence of U_2 on Y_2 passes through the concepts by the FCM(U_2, P_4, Y_2): $U_2 \xrightarrow{0,75} P_4 \xrightarrow{0,22} Y_2$, i.e. the managing concept increases the intermediate concept P_4 "Youth coverage in higher education programs", which leads to an increase in the target concept Y_2. The negative influence of U_2 on Y_2 passes through a longer route (U_2, P_4, Y_1, U_3, P_2, P_3, P_5, P_7, Y_2): $U_2 \xrightarrow{0,75} P_4 \xrightarrow{0,13} Y_1 \xrightarrow{0,19} U_3 \xrightarrow{0,37} P_2 \xrightarrow{0,33} P_3 \xrightarrow{-0,23} P_5 \xrightarrow{0,12} P_7 \xrightarrow{0,43} Y_2,$ in which the managing concept U_2, increasing the intermediate concept P_4, increases one of the target concepts Y_1 and makes changes to the managing concept U_3; increasing the managing concept U_3, in turn, has a positive effect on the state of the education system, because it increases the intermediate concepts P_2, P_3, but there is a decrease in the concepts P_5, P_7, as a consequence, and the target concept Y_2 – "The Proportion of employed graduates of educational institutions in the program of higher education – specialist's degree, master's degree" is decreased as a result. Thus, the cognitive analysis of the constructed FCM based on the algorithm of V.B. Silov allows to find possible ways of influence of the control concepts on the target concepts and to form recommendations on the expenditure of budgetary funds in the management of the quality of education.

It should be noted that the set of trajectories of transition from control concepts to target ones, defined by the cognitive map, forms fuzzy rules of decision-making on education quality management. The values of the concepts included in the transition trajectory form a training sample, which is used in the construction of neuro-fuzzy models designed to solve problems of forecasting and decision-making.

IV. Conclusion

A procedure is proposed for the implementation of the approach to the development of models of the processes of analysis and management of the quality of education, based on the definition of the trajectories of achieving the target indicators of the quality of education using the technology of knowledge engineering. The procedure involves the construction of a model of quality management of education, intelligent analysis of indicators of quality of education, cognitive modeling, including the construction of cognitive maps, the formation of trajectories between management and target concepts, the development of fuzzy rules of decision-making, and then the use of neuro-fuzzy models for decision-making on quality management of education.

The structuring of indicators characterizing the quality of education is carried out, the set of management, intermediate and target concepts is formed. A two-level functional scheme of the education quality management model is proposed, in which the lower level is implemented in the form of a closed control loop, and the upper level represents the control system using knowledge engineering technologies.

A cognitive model is constructed, based on the analysis of which the concepts and connections of the FCM are determined; the system indicators of the FCM are determined, allowing to identify the concepts that most strongly affect the quality of education, and vice versa.

The analysis of the FCM of the quality of education on the basis of mathematical algorithm of V.B. Silov is carried out: adjacency matrix, "double matrix" of positive connections, a transitively closed matrix of mutual influence of the concepts of the FCM on each other is formed, the maximum positive and negative paths (trajectories) to achieve the target concepts of the control concepts are determined.

The trajectories of transition between control and target concepts are formed, allowing to build fuzzy rules of decision-making on education quality management. It is established, in particular, that in order to improve the quality of education, the best option for the allocation of financial resources is the preferential maintenance of the concept of "Youth coverage by educational programs of higher education".

The constructed paths are the basis for the formation of a chain of fuzzy rules of decision-making type "if-then", necessary for decision-making in the management of the quality of education.

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