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THE SYNTHESIS OF STRATEGIES FOR THE EFFICIENT PERFORMANCE OF SOPHISTICATED TECHNOLOGICAL COMPLEXES BASED ON THE COGNITIVE SIMULATION MODELLING

Purpose. Improving the productivity and energy efficiency of complex technological complexes through the development and use of scenario-cognitive modeling in control systems.

Methodology. Fuzzy cognitive maps, in the form of a weighted oriented graph, were used to develop a scenario-cognitive model. As a result of the conducted research studies, a new strategy of generalization of an expert estimation of mutual influences of concepts on the basis of methods of the cluster analysis is offered.

Findings. Based on experimental research and object-oriented analysis of a complex technological complex, a structure of a fuzzy cognitive model is created. A scenario-cognitive model in the form of a weighted oriented graph (fuzzy cognitive map) has been developed, which illustrates a set of connections and the nature of the interaction of expertly determined factors. To solve the problem of impossibility of operative interrogation of experts in case of change in parameters of functioning of difficult technological complexes, expert estimations of values of weight coefficients of mutual influence of concepts are received. Cluster analysis methods were used to group expert assessments and determine a single value as a result of the research. The results of the scenario-cognitive modeling of the enterprise showed that production shutdowns and abnormal situations related to the failure of electrical equipment, deviations of the technological regime and the quality of wastewater treatment have a significant impact on the dynamics of productivity, energy efficiency and efficient use of equipment.

Originality. The new scenario-cognitive model developed for forecasting the situation in the absence of accurate quantitative information consists in creating a fuzzy cognitive map, for modeling which many parameters of complex technological complexes are expertly determined. Using the developed methodology, a degree of interaction of these parameters is found, which allows determining dynamics of change in target criteria of functioning under various management strategies.

Practical value. On the basis of the created scenario-cognitive model, software has been developed which allowed analyzing dynamics of change in productivity, energy efficiency and efficiency of use of the equipment under possible scenarios of functioning of difficult technological complexes is developed.

Keywords: *cognitive modeling, structural analysis, forecasting, fuzzy cognitive map, cluster analysis, expert assessments*

Introduction. Sophisticated technological complexes (STC) possess the following peculiarities: availability of subsystems which are interconnected by means of complicated structural and functional dependencies; high dimensionality of the control task; the necessity to make decisions under conditions of uncertainty; the need of adapting to the changing internal operation conditions and to the changing environment.

The process of major importance which connects all the main management functions of the STC is the development of control decisions since it is the speed of decision-making that determines the efficiency of the complex performance. The existing control systems do not provide for a rapid comprehensive response to short reaction time changes of the situational behavior of the object under study which depend on numerous technological and managerial factors. Simulation modelling approaches which are focused on the use of quantitative objective estimates as well as the methods of the traditional decision-making theory, which are based on the methods of choosing the best alternative from a set of clearly specified alternatives, appear to be insufficient in respect to making decisions in the systems of this kind. To date, an efficient solution to this problem is the usage of the cognitive simulation modelling which makes it possible to structurize and systematize the existing data, to identify the performance scenes for the control system and to forecast the dynamicity of achieving goals as well as to explore alternative solutions and select the very optimal ones out of them [1].

Literature review. Experts and analysts are bound to rely on their own experience and intuition in order to make decisions in the context of the lack of accurate quantitative data on the

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condition of the STC performance. The logic of the sequence of events in the multifactor field is extremely difficult to specify, which makes the task of forecasting the development of the situation part of a complicated and not always algorithm-driven process. The methods of expert questioning and identification are prominent among the existing approaches to obtaining the data on the sophisticated mutual interactions within complex objects [2].

The study on the analysis of quantitative and qualitative characteristics of the object's behavior aimed at organizing the management and decision-making strategy with regard to control under the conditions of incomplete data is presented in [3]. However, it should be noted that this work does not duly consider the ways of comprehensive assessment of the performance indicators of a complex object, taking into consideration the external and internal factors which makes it possible to constitute the relevant tactics for the strategic management under the conditions of uncertainty. The computer means of the cognitive situational simulation modelling are to be used for this purpose [4]. The forecasting objective and the objective of selecting the alternative management strategies within the cognitive approach are considered in the work [5]. Cognitive simulation models provide for conducting the analysis of the situation under consideration by means of studying the structure of mutual impacts of the concepts of a cognitive map and the dynamic analysis which is to generate the possible scenes for its development [6]. In recent years, there have been considered numerous computer systems for the decision-making support on the basis of cognitive maps and their comparative analysis is presented in [7, 8]. Alongside with that, the possibility of applying the cognitive simulation modelling to the tasks of the STC control has not been duly considered.

That being said, it is essential to determine the efficient performance strategies and scenes of a given STC under the conditions of uncertainty on the basis of the cognitive simulation modelling [9].

Purpose. The methods of the cognitive analysis of complicated situations include the following stages:

1. Defining the goals and objectives of the study.
2. The system conceptual research in the situation.
3. Structurizing the knowledge on the subject area.
4. Constructing a cognitive simulation model of the researched situation.
5. The structural analysis of the cognitive simulation model.
6. The simulation modelling based on the cognitive approach.
7. The object interpretation of the simulation modelling results.

The initial concept in the cognitive simulation modelling of complicated situations is the concept of a cognitive situation map. It presents the interaction between the object and the environment, the established cause-effect links between them and describes the way different factors affect each other in the process of their change. The mutual interaction of the expertly selected factors which describe the process of the STC performance is represented by means of a fuzzy cognitive map (model) which constitutes a signed (weighted) oriented graph [references] in which: the nodes bijectively correspond to the basis factors of the situation (the processes in the situation are described in terms of these factors); direct mutual interactions between the factors are determined. This mutual interaction can be either amplifying (positive) or inhibiting (negative) or be variable depending on the possible additional conditions. While analyzing the specific situation experts predict what changes are favorable for the most important basis target factors. The purpose of control lies in providing the desirable changes in target factors under the conditions of the situational control of the processes.

Fuzzy cognitive maps (FCMs) constitute the most effective instrument for solving the tasks of the STC research and obtaining the forecasts of its behavior under various control impacts. The general sequence of steps for building the scenes on the basis of the analysis of fuzzy cognitive maps is as follows:

1. Defining the goal of building a system.
2. Building the FCM.
3. The static modelling of the FCM.
4. The dynamic modelling of the FCM.
5. Building the scenes for the development of the situation.

Alongside with that, one of the controversial issues in building the FCM is the development of the matrix of the mutual interaction of concept at the initial stage, before the launch of the control system in the regular mode. Since most of the factual data about the object of control is obtained from expert evaluations, it is subjective to a large extent. Meanwhile, the expert evaluations on one and the same issue can differ significantly, sometimes even fundamentally. Therefore, the objective of the efficient generalization of expert evaluations in order to build an adequate FCM is relevant.

There is a task of creating a support block for the FCM performance of the synthesis of the efficient management strategies of the STC in order to generalize expert evaluations in the most preferable way in the process of the formation of a matrix of concept values.

While developing the structure of the FCM we assume that the object under study is a sophisticated organizational and technical system which consists of a following tuple

$$\langle D(t), X(t), Y(t), E(t), t\rangle, \tag{1}$$

where D stands for the actions of the enterprise; X stands for the influence of the environmental factors; Y stands for initial performance values; E stands for a set of concepts and mutual interactions between them; t stands for the operating time.

The task of the FCM is to determine the efficient strategies and scenes for the performance of a given STC of the food production facilities [10]. Let us consider the STC in the context of a sophisticated technological complex of a food production facility which is characterized by a high uncertainty of the elements it comprises while it is impossible to obtain an exact mathematical model in order to simulate the development of a system of this kind. Therefore, it is expedient to present the STC simulation model as a generalized FCM.

Results. For this purpose, it is critical to use the computer means of the cognitive simulation modelling of situations. The STC is a sophisticated system which is characterized by a large uncertainty of the elements which are its part, thus it is impossible to obtain its exact mathematical model with the purpose of simulating the development of a system of this kind [6–8]. Therefore, it is worthwhile to present the STC model as a fuzzy cognitive map. The corresponding structure of a fuzzy cognitive model has been developed in keeping with the experimental studies and the object oriented analysis of the electrotechnical complex of the food production facilities. The interval through which the scene planning is performed is set with a foundation of the technological peculiarities of the object under study, in order to determine the possibilities of improving the energy characteristics [11].

The following elements of the interaction matrix of a fuzzy cognitive map were selected expertly:

1. Intermediate concepts as follows: *E1* stands for the natural gas costs, *E2* stands for the electricity costs, *E3* stands for the electricity quality, *E4* stands for the pressure of the natural gas in the pipeline at the input of the facility, *E5* stands for the production time of technological lines, *E6* stands for the deviation of the technological process parameters, *E7* stands for the volume of the product which comes to processing, *E8* stands for the degree of the equipment use, *E9* stands for the idle time of the technological equipment, *E10* stands for the failure of the electrotechnical equipment, *E11* stands for the volume of defective products at initial start-up and production fault, *E12* stands for the quality of the water entering the wastewater treatment facilities, *E13* stands for the burst releas-

es of the product/wastewater, *E14* stands for the quality of the wastewater treatment, *E15* stands for the application of the electrodialysis wastewater treatment.

2. Input actions: *X1* stands for the cost of natural gas, *X2* stands for the cost of electricity.

3. Output actions: *Y1* stands for effectiveness, *Y2* stands for energy efficiency, *Y3* stands for the equipment efficiency use.

The STC model for the food production facilities is presented as a corresponding orgraph (a fuzzy cognitive map) which is displayed in Fig. 1 and presents a multitude of connections and the nature of the factor interaction.

Formation of the weight number of the concept mutual interaction on the basis of expert evaluations solves the problem of impossibility of prompt questioning of the experts in case of change in the functioning parameters of the STC of the food productions facilities. With the purpose of grouping expert evaluations and determining a single value, the cluster analysis was used to determine "the most significant solution possible".

The interval at which the scene planning is performed is set on the basis of the technological peculiarities of the object under study. The formation of the weight number values of the mutual impact of concepts based on expert evaluations is to solve the problem of inavailability of prompt questioning of the experts in case of the change in operation parameters of the STC of the food production facilities [12, 13]. Thus, the created FCM shall allow the scene examination of the system behavior while the values of concepts change.

A group of 5 experts is formed to conduct the examination on the basis of their own experience and the provided data in the form of a scale for quantitative record assessment. Experts are offered to fill in the table for determining the degree of mutual interaction of concepts within the range [-1, 1] in increments of 0.01, while under the negative mutual interaction of concepts the coefficient displays a negative value.

In order to increase the flexibility of the assessment, each expert identifies the possible mutual interaction values with a total of 10 variants bearing the status of extremely high probability, 5 variants of values for the group of high probability and 5 variants of values with medium probability. Thus, the matrix of expert evaluations looks as follows

$$E = e_{ij} = \begin{pmatrix} e_{11} & e_{12} & \cdots & e_{1n} \\ \vdots & | & \vdots & | \ddots | & \vdots \\ e_{m1} & e_{m2} & \cdots & e_{mn} \end{pmatrix}. \qquad (2)$$

Alongside with that, the lines correspond to the number of experts ($n = 5$), and the columns correspond to the number of judgments ($m = 20$). For the mutual interaction of each concept a separate expert matrix is created, while all the expert evaluations are further given as tables in the format defined in (2) for the convenience of data processing. The experts are interviewed by means of an individual analytical method being unaware of each other's answer. A fragment of the table of expert evaluations on the impact of the concept *E9* on the concept *E10* is presented in Fig.2.

With the aim of grouping the expert evaluations and determining a single value, it is advisable to use the cluster analysis which determines "the most possible significant solution". Unlike many other statistical procedures, cluster analysis methods are largely used at the initial stage of the research when there are no a priori hypotheses about classes [14]. Given the absence of any laws for the distribution of expert evaluations for generalization of the expert evaluations on the mutual interactions of the concepts of a fuzzy cognitive map, it is incorrect to use the methods of statistical analysis of data [15].

Before performing the clustering procedure it is essential to standardize the expert evaluations coefficients so that each variable has an average value of 0 and a standard deviation of 1, since all the cluster analysis algorithms require estimating the distances between clusters. Let us conduct the procedure of the cluster analysis by the example of expert evaluations on the impact of the concept *E9* onto the concept *E10.*

The purpose of the cluster analysis is to determine the center of the cluster with the biggest amount of data which is to be the target value of expert evaluations of the mutual interaction of concepts.

Let us use STATISTICA where classical methods of the cluster analysis are implemented, including the *k*-means method and the hierarchical clustering. At the first stage let us conduct the hierarchical classification in order to visually assess whether the values of expert evaluations form natural clusters which are to be further analyzed as well as their number. Let us select the complete linkage method as the incorporating principle and the Euclidean distance as a measure of proximity of expert evaluations. The complete linkage method defines the distance between clusters as the longest distance between any two objects in different clusters, that is to say, between "the most distant neighbors". The degree of proximity which is determined by the Euclidean distance constitutes the geometric distance in the n-dimensional space and is calculated as follows

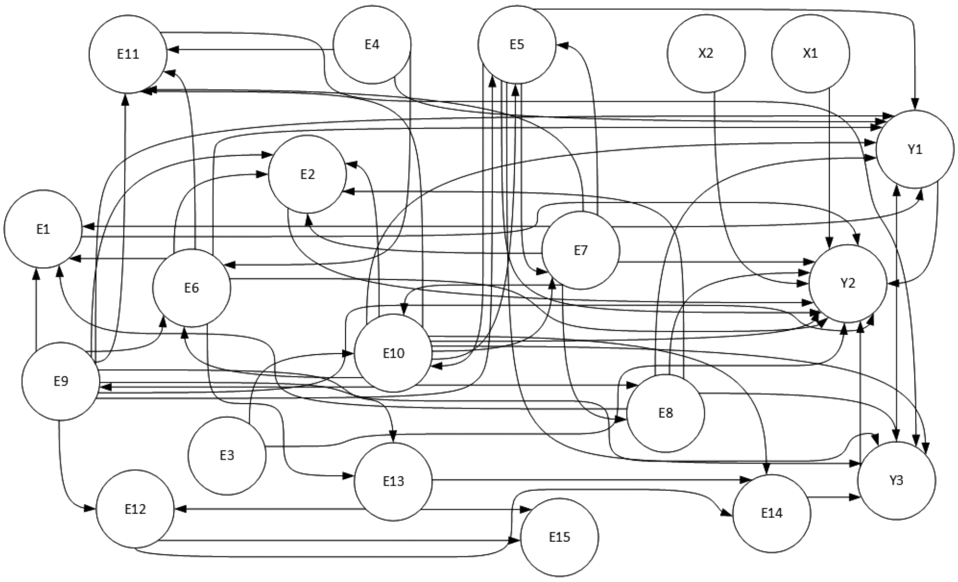
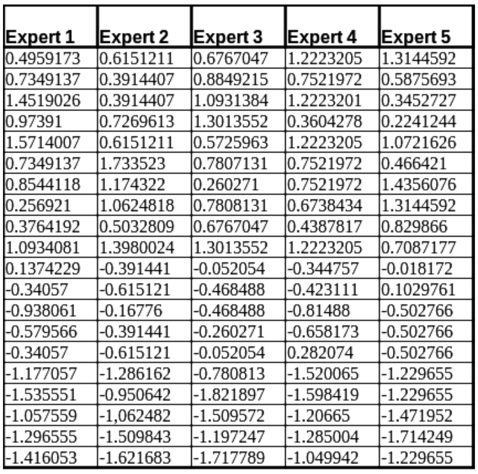


Fig. 1. The STC model of the food production facilities presented as a fuzzy cognitive map



Expert 1	Expert 2	Expert 3	Expert 4	Expert 5
0.4959173	0.6151211	0.6767047	1.2223205	1.3144592
0.7349137	0.3914407	0.8849215	0.7521972	0.5875693
1.4519026	0.3914407	1.0931384	1.2223201	0.3452727
0.97391	0.7269613	1.3013552	0.3604278	0.2241244
1.5714007	0.6151211	0.5725963	1.2223205	1.0721626
0.7349137	1.733523	0.7807131	0.7521972	0.466421
0.8544118	1.174322	0.260271	0.7521972	1.4356076
0.256921	1.0624818	0.7808131	0.6738434	1.3144592
0.3764192	0.5032809	0.6767047	0.4387817	0.829866
1.0934081	1.3980024	1.3013552	1.2223205	0.7087177
0.1374229	-0.391441	-0.052054	-0.344757	-0.018172
-0.34057	-0.615121	-0.468488	-0.423111	0.1029761
-0.938061	-0.16776	-0.468488	-0.81488	-0.502766
-0.579566	-0.391441	-0.260271	-0.658173	-0.502766
-0.34057	-0.615121	-0.052054	0.282074	-0.502766
-1.177057	-1.286162	-0.780813	-1.520065	-1.229655
-1.535551	-0.950642	-1.821897	-1.598419	-1.229655
-1.057559	-1,062482	-1.509572	-1.20665	-1.471952
-1.296555	-1.509843	-1.197247	-1.285004	-1.714249
-1.416053	-1.621683	-1.717789	-1.049942	-1.229655

Fig. 2. Standardized values of expert evaluations of the impact of E9 onto E10

$$d(x,y)=\sqrt{\sum_{i=1}^{n}(x_i-y_i)}. \qquad (3)$$

The most important result obtained by means of the tree-like clustering is a hierarchical tree (Fig. 3). On the basis of visual presentation of the results, it can be assumed that expert evaluations create three clusters. The positions of the nodes along the horizontal axis determine the distance at which the respective clusters were combined.

Further on, the k-means method is used to determine the value of the center of the cluster with the largest number of variables. The aim of the algorithm is to divide n observations by k clusters so that each observation could belong to exactly one cluster located at the shortest distance from the very observation [16].

It is essential to divide the set of observations X by k clusters $S = \{S_1, S_2, \ldots, S_k\}$, so as to minimize the sum of the squared distances from each point of the cluster to its center as follows

$$\arg\min_{S}\sum_{i=1}^{k}\sum_{x\in S_i}p, \qquad (4)$$

where μ_i stands for the centers of the clusters, $i = 1, \ldots, k$, $p(x, \mu_i)$ stands for a distance function between X and μ_i.

If the number of expert evaluations equals $= n$, then the set of expert evaluations is described by means of the following expression: $X = \{x_1, x_2, \ldots, x_n\}$. The number of clusters equals equally k , where $k \in N$, $k \leq n$.

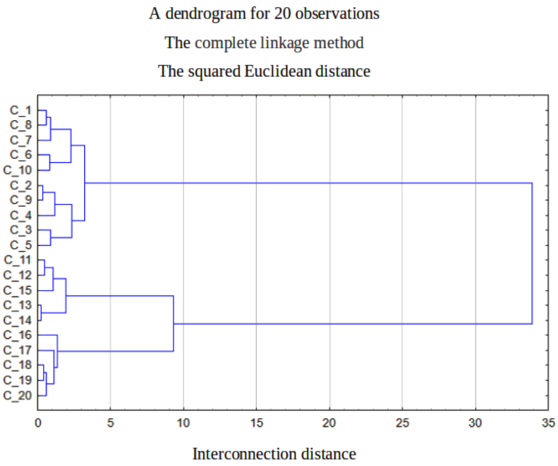


Fig. 3. The dendrogram of the dendritic pattern classification of expert evaluations for E9–E10

The algorithm by the k-means method can be represented as follows:

1. The number of clusters and the set of points are selected μ_i, $i = 1, \ldots, k$, which is considered to be the initial centers of the clusters

$$\mu_i^{(0)}=\mu_i.$$

2. The distribution of vectors by clusters is conducted

$$t:\forall x_i\in X, i=1,\ldots,n: x_i\in \overset{\Leftrightarrow}{S}_j\ j=\arg\min_k p, \qquad (5)$$

in order to perform this step of the algorithm, the Euclidean distance is calculated between the vectors $x_i \in X$, $i = 1 \ldots, n$ and the centers of the clusters $\mu_1, \ldots, \mu_k$.

3. The centers of the clusters are listed as follows

$$t\colon \forall i=1,\ldots,k\colon \mu_i^{(t)}=\frac{1}{|S_i|}\sum_{x\in S_i}x. \qquad (6)$$

4. The halting conditions are checked if $\exists i\in\overline{1,k}\colon \mu_i^{(t)}\neq$ $\neq\mu_i^{(t-1)}$, then $t = t + 1$ and there is transition to step 2, otherwise there is transition to step 5.

5. Completion of the clustering algorithm.

Having completed the clustering algorithm, it is necessary to determine the relevancy of the difference between the obtained clusters for all the expert evaluations with the help of the variance analysis (Fig. 4).

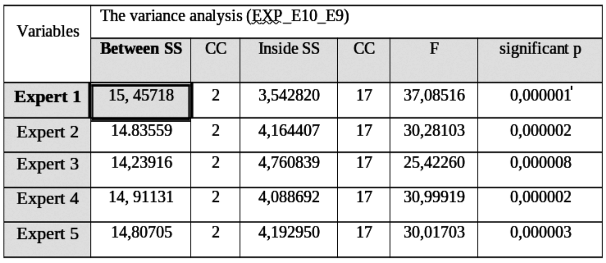
It has been concluded from the results of the variance analysis that the relevancy of $p < 0.05$, which indicates a considerable discrepancy between the clusters. In accordance with the survey statistics, three clusters are obtained (Fig. 5); each of them contains the following number of expert evaluations: cluster 1 comprises 10 variables, cluster 2–4 variables, and cluster 3–6 variables accordingly.

Thus, having determined the value of the center of cluster 1, we are to obtain the value of the expert evaluations on the impact of the concept *E9* onto the concept *E10*.

As a result of the conducted research, the following strategy for generalization of the expert evaluations on the mutual interaction of concepts has been offered:

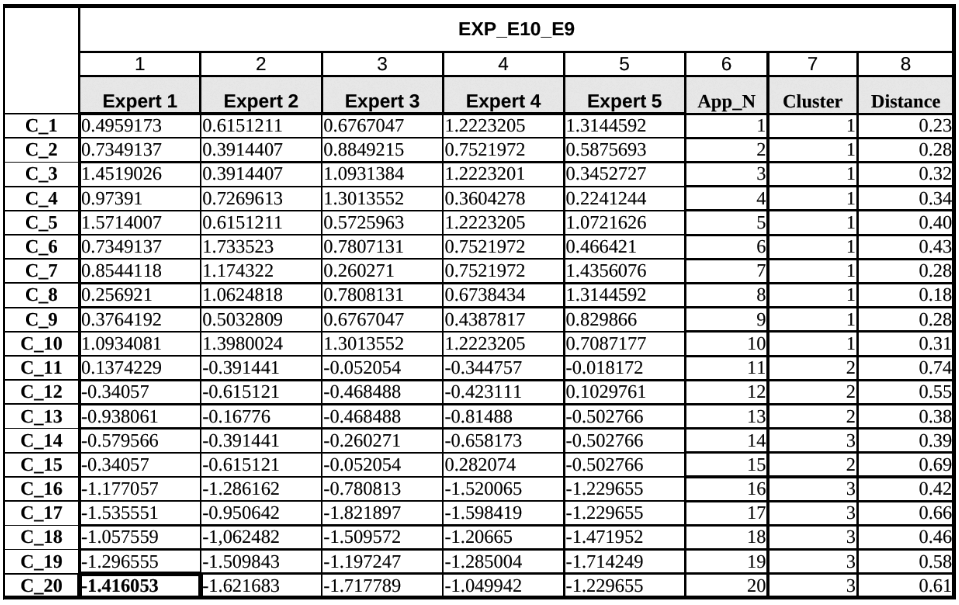
1. The formation of a matrix of expert evaluations.
2. The calculation of standardized values of expert evaluations.
3. Conducting the hierarchical classification and determining the required number of clusters.
4. Conducting the cluster analysis applying the k-means method.
5. The calculation of the cluster relevancy:
   - if the relevancy of $p < 0.05$, then go to step 6;
   - if the relevancy of $p > 0.05$, then the number of clusters is to be changed, go to step 4.
6. Determining the value of the center of the cluster with the highest number of variables.
7. Completing the clustering algorithm.

The values for all the weight numbers of the FCM concepts of the STC are calculated in accordance with the proposed method of the cluster analysis with the use of a synthesized topological map.



Variables	The variance analysis (EXP_E10_E9)					
	Between SS	CC	Inside SS	CC	F	significant p
Expert 1	15, 45718	2	3,542820	17	37,08516	0,000001'
Expert 2	14.83559	2	4,164407	17	30,28103	0,000002
Expert 3	14,23916	2	4,760839	17	25,42260	0,000008
Expert 4	14, 91131	2	4,088692	17	30,99919	0,000002
Expert 5	14,80705	2	4,192950	17	30,01703	0,000003

Fig. 4. The variance analysis of the results of the k-means method for E9–E10



	EXP_E10_E9							
	1	2	3	4	5	6	7	8
	Expert 1	**Expert 2**	**Expert 3**	**Expert 4**	**Expert 5**	**App_N**	**Cluster**	**Distance**
C_1	0.4959173	0.6151211	0.6767047	1.2223205	1.3144592	1	1	0.23
C_2	0.7349137	0.3914407	0.8849215	0.7521972	0.5875693	2	1	0.28
C_3	1.4519026	0.3914407	1.0931384	1.2223201	0.3452727	3	1	0.32
C_4	0.97391	0.7269613	1.3013552	0.3604278	0.2241244	4	1	0.34
C_5	1.5714007	0.6151211	0.5725963	1.2223205	1.0721626	5	1	0.40
C_6	0.7349137	1.733523	0.7807131	0.7521972	0.466421	6	1	0.43
C_7	0.8544118	1.174322	0.260271	0.7521972	1.4356076	7	1	0.28
C_8	0.256921	1.0624818	0.7808131	0.6738434	1.3144592	8	1	0.18
C_9	0.3764192	0.5032809	0.6767047	0.4387817	0.829866	9	1	0.28
C_10	1.0934081	1.3980024	1.3013552	1.2223205	0.7087177	10	1	0.31
C_11	0.1374229	-0.391441	-0.052054	-0.344757	-0.018172	11	2	0.74
C_12	-0.34057	-0.615121	-0.468488	-0.423111	0.1029761	12	2	0.55
C_13	-0.938061	-0.16776	-0.468488	-0.81488	-0.502766	13	2	0.38
C_14	-0.579566	-0.391441	-0.260271	-0.658173	-0.502766	14	3	0.39
C_15	-0.34057	-0.615121	-0.052054	0.282074	-0.502766	15	2	0.69
C_16	-1.177057	-1.286162	-0.780813	-1.520065	-1.229655	16	3	0.42
C_17	-1.535551	-0.950642	-1.821897	-1.598419	-1.229655	17	3	0.66
C_18	-1.057559	-1,062482	-1.509572	-1.20665	-1.471952	18	3	0.46
C_19	-1.296555	-1.509843	-1.197247	-1.285004	-1.714249	19	3	0.58
C_20	**-1.416053**	-1.621683	-1.717789	-1.049942	-1.229655	20	3	0.61

Fig. 5. The results of classifying the expert evaluations for E9−E10

The research on the FCM of the TCMS is performed having used a specialized software product FCMapper (Fuzzy Cognitive Mapper), which makes use of a mathematical generalization apparatus of the FCM. This system consists of two quite autonomous software subsystems. The first of them is implemented on the basis of the "MS Excel" spreadsheets and it is a subsystem of the FCM analysis which includes the subsystems for entering a cognitive map and obtaining a forecast of the evolving situation [17].

The cognitive map is set as a "MS Excel" spreadsheet for the structural analysis; it is exported into a file and transferred to the second subsystem of the structural analysis called "Pajek". The "Pajek" system implements the methods which make it possible to study the structure of the cognitive map as a whole, which simplifies its verification and in general makes the choice of the control factors easier while developing the control strategies in accordance with the specified goals [18].

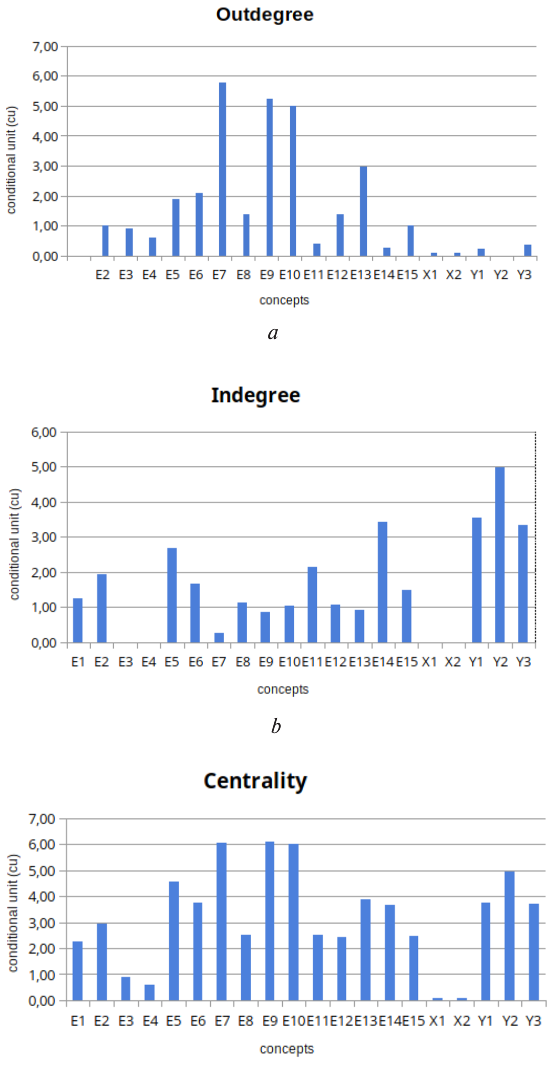
As a result of the analysis of structural characteristics of the FCM, the following results are obtained: 4 concepts perform the functions of transmitters only (Transmitter); 1 concept only receives the data (Receiver); 15 concepts are "transmitter-receivers" (Ordinary).

The main indicators of the cognitive simulation modelling are consonance, dissonance and mutual interaction of concepts. The greater the consonance is, that is to say, the greater the function is of the positive and negative impact of one concept onto the other, the more influential the parameter is considered to be. In a similar manner, the greater the dissonance is, the more dependent on the others the concept is. On the basis of the concept matrix of the FCM of the STC, the functional indices are calculated as follows (Fig. 6): consonance (Outdegree), dissonance (Indegree) and the mutual interaction of factors (Centrality).

The structural and functional characteristics of the matrix of concepts having been analyzed in terms of the importance of their impact onto the initial target parameters, and, consequently, onto the efficiency of the enterprise performance, the concepts are divided into the following three groups:

- influential concepts: *E7* (the volume of product which comes for processing), *E9* (the downtime of the technological equipment), *E10* (the failure of the electrotechnical equipment), *E13* (burst releases of the product/wastewater);

- concepts which have certain impact: *E5* (the run-time of the technological lines), *E6* (the deviation of the operation process parameters), *E12* (the initial water quality at the wastewater treatment facilities), *E1* (natural gas consump-



a

b

c

Fig. 6. Structural and functional characteristics of the matrix of the FMC concepts:

a – stands for consonance; b – stands for dissonance; c – stands for the mutual interaction of factors tion), *E2* (electricity consumption), *E14* (the quality of wastewater treatment), *E15* (the application of the electrodialysis wastewater treatment);

- concepts which have marginal impact on the initial target parameters: *E3* (the quality of electricity), *E4* (natural gas pressure in the pipeline at the input of the enterprise), *E8* (the degree of the equipment use), *E11* (the volume of defective products at initial start-up and production fault).

The possible ranges of change and the values of concepts are identified with the help of FCMapper in order to build a dynamic simulation model for forecasting the development of the situation with the purpose of improving the performance efficiency of the electrotechnical complex of the food production facilities.

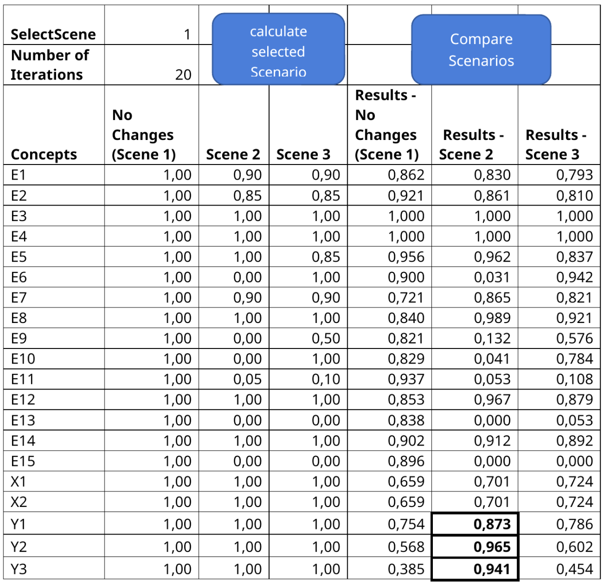
Having conducted the scene cognitive simulation modelling using the FCMapper software product (Fig. 7), the dynamics of changes in effectiveness, energy efficiency and efficiency of the equipment use have been obtained in accordance with the possible scenes.

It should be noted that in the course of implementation of the first scene the value of all the concepts are taken by the system as equal to 1.0 (maximum) automatically (by default). In the second scene, the enterprise operated in a regular mode at a capacity of the sugar-beet enterprise of 1,750 tons per day (the maximum enterprise capacity load of 2,000 tons per day). In the third scene, the enterprise operated at the same capacity but with a halt of one-hour due to the engine failure on the diffusion unit shaft. In view of the results, the target criteria for the performance of the electrotechnical complex are much lower to scene 3 than its operation to scene 2.

Conclusions. In the course of research the cognitive approach to building the simulation models of sophisticated technological complexes is reviewed, which makes it possible to implement the optimal management of the systems of the kind without constructing the exact mathematical model. The visualization of fuzzy cognitive maps, the possibilities of the numerical simulation conduct as well as a combination of the expert-based and adaptive approaches to building the model make generalized fuzzy cognitive maps a convenient means of describing systems.

As a result of the study, the following tasks have been executed:

- the FCM for the performance of the STC has been developed, including the specification of input, output and intermediate concepts;



SelectScene	1
Number of Iterations	20

Concepts	**No Changes (Scene 1)**	**Scene 2**	**Scene 3**	**Results - No Changes (Scene 1)**	**Results - Scene 2**	**Results - Scene 3**
E1	1,00	0,90	0,90	0,862	0,830	0,793
E2	1,00	0,85	0,85	0,921	0,861	0,810
E3	1,00	1,00	1,00	1,000	1,000	1,000
E4	1,00	1,00	1,00	1,000	1,000	1,000
E5	1,00	1,00	0,85	0,956	0,962	0,837
E6	1,00	0,00	1,00	0,900	0,031	0,942
E7	1,00	0,90	0,90	0,721	0,865	0,821
E8	1,00	1,00	1,00	0,840	0,989	0,921
E9	1,00	0,00	0,50	0,821	0,132	0,576
E10	1,00	0,00	1,00	0,829	0,041	0,784
E11	1,00	0,05	0,10	0,937	0,053	0,108
E12	1,00	1,00	1,00	0,853	0,967	0,879
E13	1,00	0,00	0,00	0,838	0,000	0,053
E14	1,00	1,00	1,00	0,902	0,912	0,892
E15	1,00	0,00	0,00	0,896	0,000	0,000
X1	1,00	1,00	1,00	0,659	0,701	0,724
X2	1,00	1,00	1,00	0,659	0,701	0,724
Y1	1,00	1,00	1,00	0,754	**0,873**	0,786
Y2	1,00	1,00	1,00	0,568	**0,965**	0,602
Y3	1,00	1,00	1,00	0,385	**0,941**	0,454

Fig. 7. Results of scenario-cognitive modeling of dynamics of change in target criteria of functioning of STC of the sugar factory

- a new strategy of generalization of expert evaluations on the mutual concept interaction on the basis of methods of the cluster analysis has been offered;
- scene cognitive simulation models have been developed in order to provide for the prompt determination of the measure of the target indicators of the enterprise performance on the basis of the technological and statistical analysis of the enterprise.

Analyzing the obtained results of the scene cognitive simulation modelling, we can claim that production halts and emergency situations related to the failure of the electrotechnical equipment, the deviation of the production cycle and the quality of the wastewater treatment have significant impact on the time history of effectiveness, energy efficiency and the efficiency of the equipment use, that is to say, the developed approach to establishing the efficient modes of operation of the STC of the food production facilities appears to be appropriate.

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Синтез стратегій ефективного функціонування складних технологічних комплексів на основі когнітивного моделювання

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Мета. Підвищення продуктивності та енергоефективності функціонування складних технологічних комплексів за рахунок розробки й використання сценарно-когнітивного моделювання в системах управління.

Методика. Для розробки сценарно-когнітивної моделі використані нечіткі когнітивні карти, у вигляді зваженого орієнтованого графа. У результаті проведених досліджень запропонована нова стратегія узагальнення експертної оцінки взаємовпливів концептів на основі методів кластерного аналізу.

Результати. Виходячи з експериментальних досліджень і об'єктно-орієнтованого аналізу складного виробничого комплексу створена структура нечіткої когнітивної моделі. Розроблена сценарно-когнітивна модель у вигляді зваженого орієнтованого графа (нечіткої когнітивної карти), що ілюструє множину зв'язків і характер взаємодії експертно визначених факторів. Для вирішення проблеми неможливості оперативного опитування експертів у разі зміни параметрів функціонування складних технологічних комплексів отримані експертні оцінки значень вагових коефіцієнтів взаємовпливу концептів. Для групування експертних оцінок і визначення єдиного значення в результаті проведених досліджень використані методи кластерного аналізу. Отримані результати сценарно-когнітивного моделювання підприємства показали, що зупинки виробництва й нештатні ситуації, що пов'язані із відмовою електротехнічного обладнання, відхиленням технологічного режиму та якістю очищення стічних вод, мають суттєвий вплив на динаміку зміни продуктивності, енергоефективності та ефективності використання обладнання.

Наукова новизна. Розроблена нова сценарно-когнітивна модель для прогнозу розвитку ситуації в умовах дефіциту точної кількісної інформації полягає у створенні нечіткої когнітивної карти, для моделювання якої експертно визначено множину параметрів функціонування складних технологічних комплексів. За допомогою розробленої методики встановлена ступінь взаємовпливу цих параметрів, що дає змогу визначити динаміку зміни цільових критеріїв функціонування за різних стратегій управління.

Практична значимість. На основі створеної сценарно-когнітивної моделі розроблено програмне забезпечення, що дозволило аналізувати динаміку зміни продуктивності, енергоефективності та ефективності використання обладнання за можливими сценаріями функціонування складних технологічних комплексів.

Ключові слова: *когнітивне моделювання, структурний аналіз, прогнозування, нечітка когнітивна карта, кластерний аналіз, експертні оцінки*

Синтез стратегий эффективного функционирования сложных технологических комплексов на основе когнитивного моделирования

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Цель. Повышение производительности и энергоэффективности функционирования сложных технологических комплексов за счет разработки и использования сценарно-когнитивного моделирования в системах управления.

Методика. Для разработки сценарно-когнитивной модели использованы нечеткие когнитивные карты, в виде взвешенного ориентированного графа. В результате проведенных исследований предложена новая стратегия обобщения экспертной оценки взаимовлияния концептов на основе методов кластерного анализа.

Результаты. Исходя из экспериментальных исследований и объектно-ориентированного анализа сложного производственного комплекса создана структура нечеткой когнитивной модели. Разработана сценарно-когнитивная модель в виде взвешенного ориентированного графа (нечеткой когнитивной карты), что иллюстрирует множество связей и характер взаимодействия экспертно определенных факторов. Для решения проблемы невозможности оперативного опроса экспертов в случае изменения параметров функционирования сложных технологических комплексов получены экспертные оценки значений весовых коэффициентов взаимовлияния концептов. Для группировки экспертных оценок и определения единого значения в результате проведенных исследований использованы методы кластерного анализа. Полученные результаты сценарно-когнитивного моделирования предприятия показали, что остановки производства и нештатные ситуации, связанные с отказом электротехнического оборудования, отклонением технологического режима и качеством очистки сточных вод, имеют существенное влияние на динамику изменения производительности, энергоэффективности и эффективности использования оборудования.

Научная новизна. Разработанная новая сценарно-когнитивная модель для прогноза развития ситуации в условиях дефицита точной количественной информации заключается в создании нечеткой когнитивной карты, для моделирования которой экспертно определено множество параметров функционирования сложных технологических комплексов. С помощью разработанной методики установлена степень взаимовлияния этих параметров, что позволяет определить динамику изменения целевых критериев функционирования при различных стратегиях управления.

Практическая значимость. На основе созданной сценарно-когнитивной модели разработано программное обеспечение, что позволило анализировать динамику изменения производительности, энергоэффективности и эффективности использования оборудования по возможным сценариям функционирования сложных технологических комплексов.

Ключевые слова: *когнитивное моделирование, структурный анализ, прогнозирование, нечеткая когнитивная карта, кластерный анализ, экспертные оценки*

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