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Ihor SHEVCHENKO, Denys VASYLIEV, Serhii PRYTCHYN, Andrii SAMOILOV

Kremenchuk Mykhailo Ostrohradskyi National University, Kremenchuk, Ukraine

BUSINESS PROCESSES MONITORING BASED ON FUZZY COGNITIVE MAPS

*The **subject matter** of the article is a toolkit and monitoring processes of weakly structured business processes using fuzzy cognitive maps (FCMs). The **goal** is to create a model for monitoring and forecasting the course of business processes based on the FCMs, which provide flexibility and the ability to adapt to the conditions of changing circumstances in the process to be monitored, as well as insurance of the possibility of applying unstable FCM.s The **task** is to develop a formal monitoring system model; develop a computational FCM model; develop a method of using unstable FCMs: to develop a method for creating and using an FCM model. The **methods** used are graph modeling methods and computational experiment methods. The following **results** were obtained. A formal model of the system of monitoring and coordination of decisions regarding the course of business processes has been developed. A model of a weighted semantic graph was developed, which includes three types of vertices, namely, input vertices that will receive subjective evaluations of users regarding the course of the process, intermediate vertices that correspond to factors important from the perspective of the decision-maker, and final vertices that reflect integral evaluations of the quality of business process execution. A computational FCM model has been developed, which can adapt to the specifics of business logic due to the flexible adjustment of memory parameters and connections between FCM nodes. A method of using unstable FCMs has been developed. A methodology for creating and using FCMs designed for monitoring weakly structured business processes has been developed. **Conclusions**. The scientific novelty of the work is as follows: the model for monitoring and forecasting the course of business processes due to the use of a fuzzy cognitive map, in which the parameters of the importance and node memory and connections provide additional flexibility and the possibility of coordination and adaptation in the conditions of changing circumstances in the process to be monitored has been improved; a method of using unstable FCMs by setting limits on the values of the nodes excitation and using as a measure of excitation not only stable excitation values of FCM nodes but also the rate of growth of excitation values as an indicator of trends, which allows monitoring and forecasting the course of business processes has been proposed.*

Keywords: *business processes monitoring; fuzzy cognitive maps; graph model; computational model; unstable cognitive maps; knowledge base.*

Introduction

It is impossible to ensure the reliable operation of any organizational and technical system without monitoring the implementation of business operations and business processes (BP). In recent years, monitoring compliance of business processes with certain norms, restrictions, and rules has become one of the main problems. Monitoring involves not only constant observation of the process for control purposes but also includes the ability to predict future violations of compliance and provides profound feedback for management decisions.

One of the most important tasks for us is predicting critical situations in the BP implementation, due to the fact that any critical situation reduces the BP quality, slowing down its progress and increasing the risks of increasing the cost of delays. Analyzing the features of various business processes, it is possible to identify an array of potentially critical situations: delays in function execution time, cancellation of previously performed actions, errors in the execution of operations, risks related to the terms of execution, and increasing costs.

Works [1, 2] highlight one of the approaches in the field of organizational management, in which management is regarded as a process of making agreed decisions between responsible persons (actors) based on a general understanding of the situation. According to the author [1], this point of view becomes the basis of a new intersubjective theory of situational management, in which not only and not so many management object models should be considered, but also activity models of groups implementing object management. But in this work, there is no formalized description and algorithms for calculating the influence of some actors' opinions on the other actors' opinions.

The work [2] presents a method of supporting participation in decision-making processes and modeling situations without the need for face-to-face interaction. It is emphasized that there is an increased need for structured methods to implement collective decision-making processes in order to obtain knowledge from stakeholders and present this knowledge in an appropriate model. The proposed technique involves the use of fuzzy cognitive maps (FSMs). Such a model might become the basis for the development of BP monitoring systems.

In [3], a decision support model is proposed that integrates fuzzy multi-criteria decision-making with fuzzy cognitive maps to prioritize strategies for improving the productivity of construction works. By means of FCM, cause and effect relationships between operating factors and project characteristics are clarified.

The work [4] describes an automatic model that is intended for BP monitoring. The model takes into account workplace conditions and the status of applications for business operations. The model tracks the course of business processes that progress across multiple workplaces. Due to the regular fixation of states in time, it is possible to form a section of the state of the organizational and technical system (OTS) at any point in time and to optimize the distribution of loads among workplaces. The disadvantage of this model is the impossibility of taking into account the information event relationship occurring in OTS. Meanwhile, this relationship affects the course of business processes and decision-making regarding their correction.

Therefore, the FCM application in the tasks of information structuring and decision-making is a relevant area of business process modelling and monitoring.

1. Analysis of works related and objectives

The start of modeling with FCM is the work by B. Kosko [5], where he proposed a computational model that uses a graphical representation of the connections between concepts of the subject area and a cyclic recalculation of the nodes-concepts excitation level. It was he who called the model a fuzzy cognitive map, i.e. FCM. Therefore, FCM is a graph model that presents cause and effect relationships between nodes, which makes it possible to describe its behaviour in a simple and symbolic way. In FCM graphs, nodes represent concepts and arcs represent the assumed relationships between these concepts. As noted in works [6, 7, 8], experts can apply their knowledge in a certain area to develop FCMs, firstly, by defining the main concepts involved and, secondly, by indicating cause and effect relationships between these concepts. The last step is to determine the power of cause and effect relationships using either clear numerical values in the range [-1,1] or linguistic variables and values, which are defuzzified into numerical values in the second step [7]. The results of the FCM successful application may be the following: the confidence of a decision-makers (DM) group which is sufficient enough to make a decision; a deeper understanding of the problem situation by the DM group; coordination of positions in a group of stakeholders, as well as the forecast of future events [9, 10]. In particular, work [10] presents the calculation of FCM system parameters, such as the degree of influence of a certain concept on another concept, the influence of a concept on a system, and the influence of a system on a certain concept.

One of the FCM problems is that the number of experts and the difference in their opinions regarding the causal power of connections also affect the final result, which is one of the important disadvantages of this approach, as it is indicated in [10]. Adjusting the power of relationships in the process of coordinating experts' opinions is a non-trivial task. It is not allowed to change the values of the relationships freely because they reflect some business logic. This primarily concerns the monitoring of semi-structured BP. Therefore, it is necessary to have a flexible mechanism for the connection weights adjusting, which works smoothly and takes into account previous values in the process of calculating new values.

The second problem of FCM use is instability. When the strength of the connections is agreed upon, it may turn out that the FCM is unstable to external stimuli, which are evaluations of factors affecting the course and quality of BP execution. This property again depends on the set of values of weighting coefficients of the connection matrices between nodes. The authors of works [11 – 13] believe that this problem should be eliminated by artificially controlling the FCM operation mode. At the same time, changes in the values of FCM connection coefficients are carried out according to a certain algorithm. But, again, those values and their signs are set by experts in the problem area. Therefore, the business logic of the problem area may be violated when the connection values are changed being controlled by a certain algorithm.

The above-mentioned problems remain unsolved. Therefore, the goal of our work is to create such a model of monitoring and forecasting the course of business processes based on FCMs, which provides flexibility and the possibility of adaptation in the conditions of changing circumstances in the process to be monitored, as well as ensuring the possibility of unstable FCM applying.

2. Formal model of the subsystem of monitoring and coordination of decisions

When solving the problem of supporting decision-making in the management of complex organizational and technological systems, the fact that the number of possible states of the system usually significantly exceeds the number of feasible solutions should be taken

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into account. In this case, it is necessary to classify states based on a set of relevant features. But each state of the controlled system is characterized by the states of its elements and aggregation of relationships performed on a set of elements, which makes it practically impossible to describe them in the form of a simple aggregation of relationships, as it is done in most pattern recognition models existing [2]. For this purpose, the apparatus of semantic networks and cognitive maps, which are weighted graphs and have wide possibilities for presenting various information about the control object are often used in the systems of the considered class. So, the task of forming classes of controlled system states can be posed as a task of classification on a set of weighted structures-graphs that serve to present data and knowledge about the object.

Formally, the model of the subsystem of monitoring and coordination of decisions will be represented in the form of

$$MCD = <P, QPP, SS, RR, RE, KB, DB>, \quad (1)$$

where P is the process to be monitored;

QPP is a set of process indicators; SS is a set of signs of the situation; $RR \subseteq SS \times QPP$ is mapping of a set of signs of the situation to a set of indicators characterizing the process state; RE is a model of evaluation alignment; KB is a knowledge base on decision-making; DB is a database.

It is necessary to develop a set of models that transform the primary evaluations of the process indicators into the signs of the situation and allow taking into account the mutual influence of evaluations and aligning the evaluation results for the purpose of making organizational decisions.

3. Computational FCM model

Let us consider such a problem [14]. There is a set of controlled system states Z described by a weighted semantic graph (SG). Further, let a certain K class of the system states be included in Z: $K \subseteq Z$.

Let us denote by v_k and w_k the training samples of examples and counterexamples of the K class:

$$v_k \subseteq K; \; w_k \cap K = \varnothing.$$

It is necessary to build an algorithm for the Aк classification, which allows determining the belonging of an arbitrary object $s_0 \in Z$ of the K class.

The Aк algorithm will be presented in the form of a combination of two algorithms: the A1 algorithm for calculating the state of the object, which is presented in the SG form, after external influence, and the A2 algorithm for recognizing the current situation concerning some R_K generalized representation of the K class, obtained as a result of the A1 algorithm operation. Such a model is designed for implementation in decision-making systems with different organizational structures that meet the following fairly general requirements:

- the structures of the T_j, j=1, ..., n sets of the objects of the subject area given intersect only by inclusion;

- each state of the controlled system must be completely specified by defining the set of relationships that are performed at the moment on a set of its elements.

The ω_i types of the V_i vertices of SG can acquire the following values:

1. Type $\omega_i=(N_j,x_j)$, where N_j is a concept − object that has an evaluation of $x_j \in X$ from the set of X calculated criteria. This concept has only input arcs.

2. Type $\omega_i= P_j$, where $P_j \in P$ is an intermediate concept, which has a numerical value calculated according to some expression. Each intermediate concept has at least one arc leading to another concept vertex.

3. Type $\omega_i=<O_j,r_j>$, where O_j, j=1...k, is the name of an aspect feature that the monitored object can possess, k is the total number of such features, and r_j is the value of the given feature. In this case, the V_i vertex is called characteristic and at least one arc going from this vertex to some conceptual vertex is incident to it.

Let us apply the basic FCM principles [7] and construct a network in which the values of node activity parameters, node memory, and connections change along the calculation cycle, adapting to new circumstances. The calculation takes place over several iterations of the A1 algorithm, during which the change in the states of the network nodes is recorded. After that comes the stage of analyzing the situation, which is the A2 algorithm. The situation is represented by node activity levels, which are interpreted by fuzzy statements. Each situation has subsets of patterns: deterioration, sustainable development, and improvement. If a node is not needed for the current analysis session, the corresponding knowledge base pattern must have a special symbol.

Let us construct a computational model of the FCM. The basis of the computational model is the G=(C, W) graph, where there is the C set of nodes, which includes vertices of the three types indicated above and the $W=\{w(c_i, c_j)\}$ set of connections. Next, it is necessary to distinguish the $X=\{x_1, x_2, \dots, x_n\}$ set of input influences, the $E=\{e_1, e_2, \dots, e_p\}$ set of intermediate concepts, and the $Y=\{y_1, y_2, \dots, y_m\}$ set of output signals generated by vertices of the (N_j, x_j) type.

The FCM functioning in the direction from the input to the output is determined by the Y=F(X, E, W) dependence. Due to the presence of inevitable feedback, the functional dependence takes a recurrent form

$$E(k) = F1\left[X(k-1), E(k-1), W\right],$$
$$Y(k) = F2\left[X(k), E(k), W\right], \qquad (2)$$

where k is a number of the calculation tact.

The network, which functions according to the outlined concepts, allows one to determine the current state of the controlled object by varying the values of the X components vector and the W connection matrix.

Let us determine the excitation and memory characteristics for FCM nodes and connections. To describe restrictions on the node activity level, it is advisable to use the following sigmoidal function

$$G = \frac{a}{1 + \exp(-\alpha \cdot S + b)} + c, \qquad (3)$$

where the a, b, and c parameters determine the limits of the node's activity change, α − parameter of the steepness of the sensitivity change, S is the sum of the node input signals.

This function allows us to adjust the limits and the desired steepness of the change in the degree of node activity when the value of the input signal sum changes.

The memory parameter indicates a gradual decrease in the degree of relevance of the model current state. The value of the memory parameter will be determined as the retention factor of the previous node excitement value, in the same way, using the sigmoid function (2), but this function argument will be the parameter of the importance of the corresponding node concept. That is, for more important concepts, the memory of previous values is preserved longer. Parameters of the concepts and connections' importance serve as elements of the network's initial settings. Their value (in the range from 0.1 to 1.0) is entered by the decision-maker (DM) seeking guidance from the analyst.

Taking into account the above mentioned, let us write down the formula for calculating the node excitations under the influence of the weighted sum of input signals arriving at the i-th FCM node from all the j-th nodes (i≠j):

$$P_i^{t+1} = G\left(\mu_i P_i^t + (1-\mu_i)\sum_{j=1}^{N} w_{ij}^{t+1} P_j^t\right),$$
$$i = \overline{1,N},\ j = \overline{1,N}, \qquad (4)$$

where w_{ij}^{t+1} is a connection coefficient;

μ_i – is the memory coefficient of the i-th node.

To use FCM as a tool for aggregating the opinions of a group of experts, it is necessary to determine adequate values of the relationships between factors, which is difficult if the map has a large number of vertices. To automatically adjust the connection values, let us use a learning algorithm, namely, the connection coefficients are adjusted according to the well-known Hebb formula [15], taking into account the connection memory parameter:

$$w_{ij}^{t+1} = \gamma_{ij}(1-c_{ij})P_i^t P_j^t + c_{ij} w_{ij}^t, \qquad (5)$$

where γ_{ij} is the proportionality factor;

c_{ij} is the connection memory coefficient.

The memory coefficient allows you to adjust the dynamics of the communication parameter change, avoiding large changes in those values that were set by experts taking into account the business logic of the processes modelled.

Therefore, an improved model for monitoring and forecasting the course of business processes is proposed through the use of a fuzzy cognitive map, in which the parameters of the node importance and node memory and connections that change over time provide additional flexibility and the possibility of adaptation under conditions of changing circumstances in the process, which is subjected to be monitored.

Next, it is necessary to have a method of using unstable FCM.

4. Method of using unstable FCM

The proposed method involves the following stages:

1. Fixing the initial values of FCM connections. At this stage, it is necessary to obtain from the experts their subjective evaluations of the connection values and to calculate the average values of each connection.

2. Calculate the maximum eigenvalue of the connection matrix and determine the properties of the FCM in terms of resistance to excitations. This information is taken into account during computational experiments with FCMs.

3. Form a computational FCM model in an Excel spreadsheet. Calculate transient processes in the FCM, alternately giving increments of the input factors values fixing the type of the transient process. During these studies, it is found the following:

- the N1 number of necessary computational iterations to achieve constant values of node activity if the FCM is resistant to excitations;
- the N2 number of necessary computational iterations to achieve certain limit values of node activity, if the FCM is unstable to excitation;
- the range of maximum node activity values at the maximum allowable increments of input factor values;

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- the rate of growth of the absolute values of the node activity of the unstable FCM. This parameter must be normalized for specific conditions specified by the values of the FCM computational model parameters. The normalized values of the growth rate of activity values are taken into account in the rules for interpreting the model state as a tendency to worsen or improve the situation.

When performing these stages, the unstable FCM can be used to analyze the state of the BP and predict its course.

5. Development of the knowledge base structure

In particular, let us pay attention to the creation of the knowledge base (KB), that is, the interpretation mechanism, which transforms the data received from FCMs into verbal statements. The KB should be comprehensive, as it should be used to solve a number of tasks, namely:

- analysis and assessment of the state and dynamics of changes in the BP state;
- forecasting trends in the changes of the BP state;
- drawing up recommendations for DM to eliminate risks and problems.

Therefore, a method of using unstable FCMs has been formed, which allows monitoring and forecasting the course of business processes, taking into account not only the constant values of FCM nodes excitations but also the rate of absolute excitations values growth as an indicator of trends in changes in the BP state.

Let us consider the KB structure, which should interpret the results of modelling the course of the BP. Such a KB should consist of several blocks, have a hierarchical structure and use different knowledge models.

We will successively consider the stages of forming assessments and justify the required knowledge models.

The analysis and assessment of the current BP state are carried out according to the following aspects: formation of risk signs; quantitative and qualitative risks assessment; assessing the BP state by interpreting a set of risk assessments.

The task of forming risk signs and their quantitative assessment is presented as a set of mathematical expressions, i.e. in procedural form. To solve the problem of assessing the BP state, let us initially define assessment criteria. The main criteria for assessing the quality of the BP stage execution will be established as follows; CD as the degree of deviation from the fixed cost of the stage;

WC as coordination, that is, the degree of deviation from the established values of the time parameters of the beginning and end of stages and work items.

These values are presented in numerical form. To use them in the evaluation rules, a fuzzy interpretation is required, which is based on the fuzzification procedure followed by the selection of the term with the maximum degree of truth. Then, it is clear that the corresponding KB block should be represented as a fuzzy logic derivation matrix.

2. The analysis of the current state and dynamics of changes in BP is carried out on the basis of the calculation of the excitations of the active semantic network (ASM) nodes, which are interpreted as signs of project states. Then, the excitation values must be transformed into a verbal form with the help of a fuzzy interpreter and can be applied in the left parts of the production rules of prediction. Therefore, this KB block will be represented as a fuzzy derivation matrix.

3. Evaluation of trends is carried out using the mechanism of trend formation as a certain regularity in the sequence of evaluations of the project state. The formed link of verbal assessments is compared with the trend patterns in the matrix of logic inference and a conclusion is made regarding the risk of future situations.

4. Development of recommendations for DM regarding the elimination of risks and problems should be carried out on the basis of an integrated assessment of the project's current state, predictive assessments of future states, and the significance of the named risks, that is, on the basis of preliminary conclusions, which are the results of the performance of the above-defined analysis and forecasting tasks. It is advisable to implement this KB block as a set of classic rules of the "IF ... THEN" type. This reasoning is due to the fact that a set of such rules should be open and as accessible as possible for addition and amendments without the involvement of a programmer.

Taking into account all the mentioned above, let us formally present the knowledge base in the following form:

$$F = f(D5(D3(D1,D2) \cap D4(D1,D2)) \cap D6), \qquad (6)$$

where D1 is a fuzzy estimation of risk concerning costs;

D2 is a fuzzy estimation of risk concerning terms;

D3 is a fuzzy estimation of the current BP state;

D4 is a fuzzy estimation of the BP state tendency to change;

D5 is an integral estimation of the BP state;

D6 is a certain additional feature that can be indicated by the DM.

6. Method of FCM construction and setting

An FCM instantiation is created for each BP. The instantiation may differ from the prototype in terms of the concepts' number and their names, the signs of connections, and the values of the importance of concepts and connections. The FCM setting is carried out in order to obtain adequate values of the excitation of conceptual nodes in certain situations for this BP. During the setting, the importance coefficients of FCM connections are adjusted. The method of the FCM construction and setting is described below.

Stage 1. Set the values of the main BP parameters. The main parameters include a list of stages with their names; work packages for each stage; start and end terms of all the stages and corresponding work packages; estimates of financial costs for each stage; a list of direct participants at each stage; a matrix of project responsibilities with an indication of organizations and units for each stage.

Stage 2. Set the names of the concepts according to the BP aspects (BP glossary) and the concept importance matrix for each BP stage by the method of pairwise comparisons.

Stage 3. Set the matrix of the significance of concept connections at each BP stage.

Stage 4. Select precedents from the library of test situations and prepare assessments on aspects together with the DM.

Stage 5. Perform a trial calculation on the FCM with the participation of the DM in the test situation.

Stage 6. Make several iterations of connection calculation on several test situations and average the obtained values. Record the deviation of the evaluated values obtained in the FCM from the desired values obtained from the DM.

Step 7. If the deviations from the desired values are too large, adjust the values of the relationship importance parameters and return to step 5.

End.

To carry out a general analysis of situations, it is necessary to have a methodology for determining the mutual influence of factors. The methodology has the following stages:

Alternately give unit increments to input and intermediate nodes and fix constant values of relative increments of intermediate and final nodes. If the map shows signs of instability, the excitation increment should be calculated for the last n steps of calculations from N2 steps. It was set $n=10$ in the experiments.

Create a matrix of mutual influence of factors for further analysis.

For each intermediate and final node, rank the input and intermediate nodes according to the decreasing degree of influence on the indicated node.

7. Experiments

Computational experiments with FCM were carried out in two stages. At the first stage, the limits of values of excitations and coefficients of connections were selected, and corresponding matrices were formed, which contain signs of connections, coefficients of concepts, and connections' importance. Cyclic calculations of excitations and connections were carried out in the Microsoft Excel software. This made it possible to clarify the limits of the model parameter values, at which the calculation process can be aperiodic, and have damping or diverging oscillations. During the cyclic recalculation of the FCM node excitations, a transient process is reproduced in which a change in the values of the excitations can be observed. This process is influenced by the content of the relationship matrix. If this matrix has eigenvalues whose modulus is less than unity, the FCM is stable and the transition process reaches a steady state. Fig. 1 shows transients in a stable map.

If there is at least one eigenvalue whose modulus is more than unity, the FCM is unstable and the transient process is divergent (Fig. 2). On the other hand, there is the so-called structural instability. It is determined by the number of positive and negative feedback cycles. It is believed that in the presence of structural instability, it is necessary to change the FCM structure. But we disagree with that provision on the grounds that the experts who create FCMs reach an agreement among themselves on the structure of FCMs and the values of the connections. That's why we think it's necessary to have a method of using unstable maps.

If the FCM turns out to be stable (Fig. 1), use it, it is enough to set the range of maximum excitement values and tie a scale of verbal evaluations to it. If the FCM is unstable (Fig. 2), it is necessary to calculate the increase in excitation over the last n calculation steps.

Fig. 3 shows a certain increase in excitation values for FCM nodes at the stage of determining the mutual influence of nodes.

Fig. 3 demonstrates that a single increase in the excitation of node 4 led to a certain increase in the excitation of all nodes, including node 4 itself, after a cyclic calculation. It proves that the map has positive feedback.

8. Example of implementation

At the second stage, a prototype of the program was developed, the functionality of which allows you to

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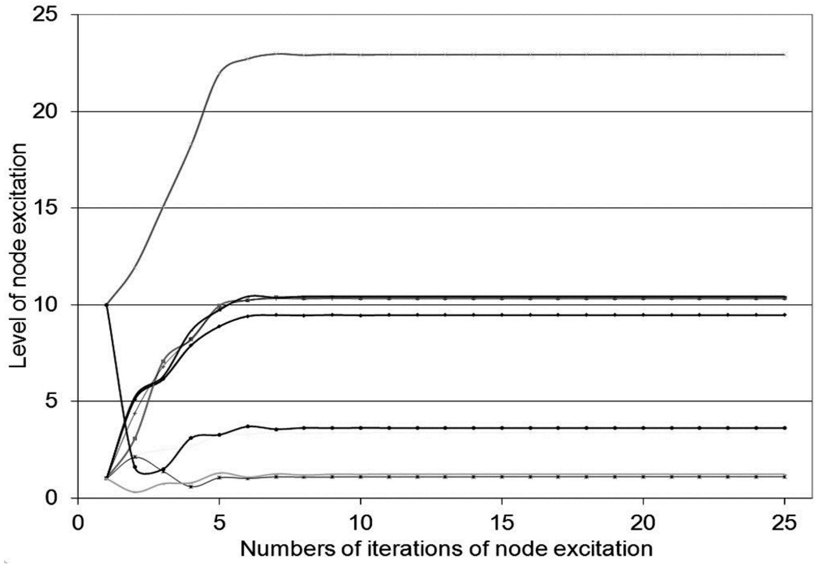

Fig. 1. Transitional process for a stable card

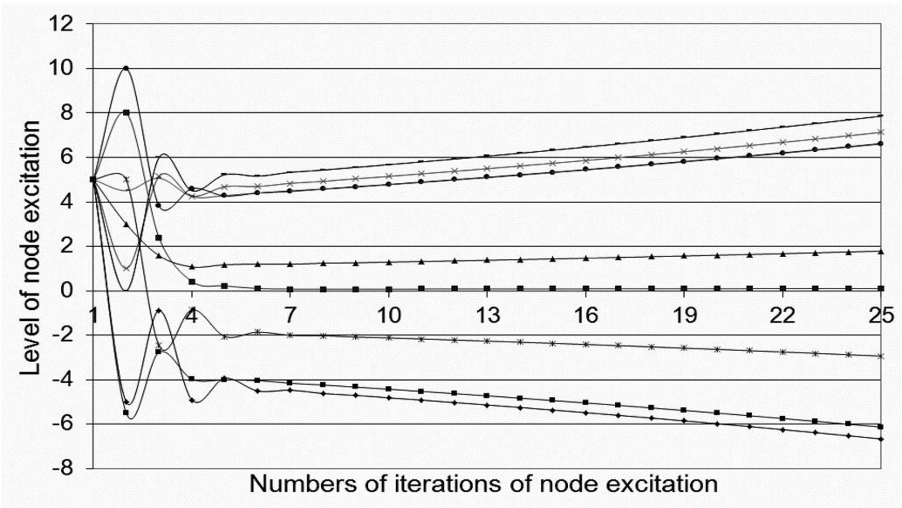

Fig. 2. Transition process for an unstable map

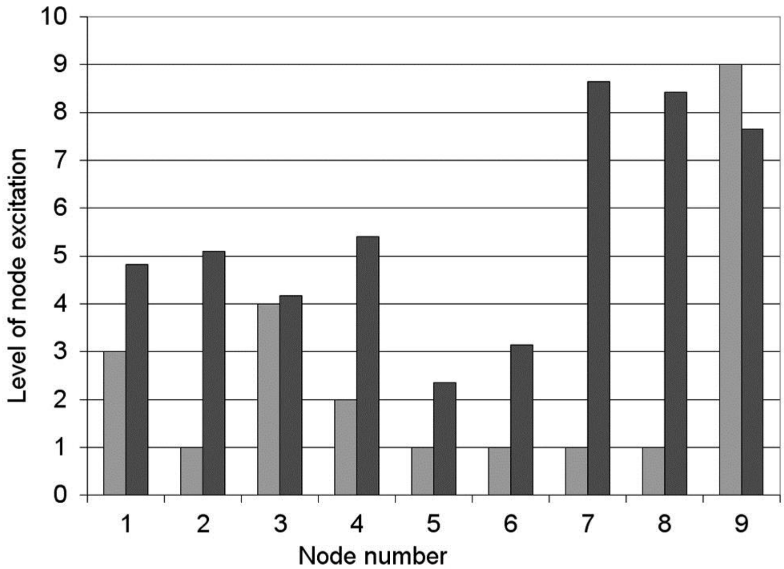

Fig. 3. The picture of changes in node excitations after a unit increment at node 4

conduct a business game with several participants and observe the process of FCM setting up and the process of agreeing to the participants' opinions regarding the assessment of the virtual control object state. The plot of the business game was the promotion of the Buzzing City multimedia project. As concepts, risks related to the terms of stage completion, risks related to the increase in the scope of work, costs, etc., were applied. During the game, the participants had to enter their risk assessments, general assessments of the quality of work execution, and general assessments of the project state. The purpose of the experiment was to determine the participants' training time, the time of inputting the values of the network parameters, the time of agreeing to the estimates between the participants, and the time of FCM setting up by adjusting the values of the importance coefficients of concepts and connections. In the business game, integer scores from 1 to 9 were used. These scores were changed arbitrarily during the calculation process, but in further interpretation, a transition to an integer score scale is made.

The program allows you to enter the initial project data, calculate the state of the map, and interpret the received excitation values in verbal evaluations. In the process of testing, users had the opportunity to adjust the values of the coefficients of the importance of concepts and connections. This made it possible to determine the time required for setting up the FCM.

Three theoretical and practical sessions were held to train users. At the first session, the principle of the program operation and its possibilities, as well as the plot of the business game, were demonstrated to the participants. In the second session, the participants chose the DM who had to enter the values of the network parameters and the initial parameters values under the tutor's supervision. Then, the business game started, which continued during the third session. In total, 4 hours were spent on training procedures. One hour was spent on entering parameter values, taking into account the fact that the DM constantly consulted with the tutor. Depending on the situation, it took from 5 to 15 minutes to reconcile the estimates, taking into account the adjustment of the values of importance.

9. Results

So, the testing of the FCM model and the program demonstrated that the models and methods are functional. During the execution of the business process, the program receives data on risks and evaluations according to certain criteria. Simultaneously, a recalculation of the excitation levels in the nodes occurs as well as a recalculation of the connections, if it is necessary. The levels of threat concepts, stages of readiness, and evaluation in points, which are assigned by specialists through their interfaces, are changing. The recalculation of the node excitation occurs after the intervention of any employee who has access rights to certain inputs. Other employees receive the recalculated evaluations of the concepts and have the opportunity to make their amendments, which will also be taken into account in the next recalculation of the FCM node excitation. In this way, a coordinated collective vision of the controlled process state is derived.

The application of individual memory parameters of nodes and connections that change over time provides additional flexibility to the model and the possibility of its adaptation in the conditions of changing circumstances in the process to be monitored. The ability to experiment by changing the values of the inputs provides the ability to predict the states of the control object. Since each responsible employee can enter their own assessments of the object state, which will affect all concepts and relationships, there is an opportunity to develop and make coordinated decisions to troubleshoot.

Conclusions

An improved model for monitoring and forecasting the course of business processes is proposed due to the use of a fuzzy cognitive map, in which the parameters of the node importance and node memory and connections that vary over time provide additional flexibility and the possibility of coordination and adaptation in the conditions of changing circumstances in the process, which is a subject to be monitored.

A method of using unstable FCM is proposed by setting limits on node excitation values and using as a measure of excitation not only stable excitation values of FCM nodes but also the rate of excitation values increase as a trend indicator, which makes it possible to monitor and forecast the course of business processes.

The method of the FCM constructing and adjusting, as well as the simplified method of determining the mutual influence of factors, which makes it possible to analyze the circumstances and course of the BP quickly and conveniently, are outlined.

A knowledge base structure has been developed that is to interpret the results of modeling the course of BP. The knowledge base consists of several blocks, has a hierarchical structure, and uses various knowledge models, which allow the evaluation of the state of the business process based on verbal assessments, identify trends in the course of the process, and generate recommendations for eliminating distress situations.

The ability to use unstable FCM for decision-making support is a step in the direction of simplifying approaches to using FCM in many applications, due to the fact that analyzing the stability of cognitive maps

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takes a lot of time and effort. A simplified method for determining the mutual influence of factors without complex analysis of many interconnected feedback loops on the map graph is also proposed.

The testing of the FCM model and the program that implements it demonstrated that the models and methods are functional and allow obtaining and harmonizing a collective vision of the state and forecast of the course of the controlled process.

In the future, it is planned to develop, on the basis of the proposed approach, information technology for monitoring and forecasting the course of a set of business processes (programs, projects) implemented in the municipal sphere.

Authors' contribution: a computational FCM model which is able to adapt to the peculiarities of business logic due to flexible regulation of memory parameters and connections between FCM nodes was developed, by **Denys Vasyliev**; a method of using unstable FCM was developed by **Denys Vasyliev**; the structure of the knowledge base, which should interpret the results of modeling the course of business processes, was developed by **Denys Vasyliev**; experimental studies were conducted and relevant results were obtained by **Andrii Samoilov** and **Serhii Prytchyn**; the review and analysis of references devoted to the problem of weakly structured business processes and unstable FCM as well as the introductory part were prepared by **Ihor Shevchenko**; the concept of using unstable FCM was proposed by **Ihor Shevchenko.**

All authors have read and agreed with the published version of the manuscript.

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МОНІТОРИНГ БІЗНЕС-ПРОЦЕСІВ НА ОСНОВІ НЕЧІТКИХ КОГНІТИВНИХ КАРТ

І. В. Шевченко, Д. О. Васильєв, С. Е. Притчин, А. М. Самойлов

Предметом вивчення в статті є інструментарій та процеси моніторингу слабкоструктурованих бізнес-процесів за допомогою нечітких когнітивних карт (FCM). **Метою** є створення моделі моніторингу та прогнозування перебігу бізнес-процесів на базі FCM, в якої забезпечується гнучкість та можливість адаптації в умовах зміни обставин у процесі, що підлягає моніторингу, а також забезпечення можливості застосування нестійких FCM. **Завдання:** розробити формальну модель системи моніторингу; розробити обчислювальну модель FCM; розробити метод використання нестійких FCM; розробити методику створення та використання моделі FCM. Використовуваними **методами** є: методи графового моделювання, методі обчислювального експерименту. **Отримані такі результати.** Розроблено формальну модель системи моніторингу та узгодження рішень щодо перебігу бізнес-процесів. Розроблено модель зваженого семантичного графу, яка включає три типи вершин, а саме – вхідні вершини, що отримають суб'єктивні оцінки користувачів щодо перебігу процесу, проміжні вершини, що відповідають факторам, важливим з точки зору особи що приймає рішення, та кінцеві вершини, які відображають інтегральні оцінки якості виконання бізнес-процесу. Розроблено обчислювальну модель FCM, яка здатна адаптуватися до особливостей бізнес-логіки за рахунок гнучкого регулювання параметрів пам'яті та зв'язків між вузлами FCM. Розроблено метод використання нестійких FCM. Розроблено методику створення та використання FCM, що призначена для моніторингу слабкоструктурованих бізнес-процесів. Розроблено базу знань для інтерпретації виходів FCM. **Висновки.** Наукова новизна роботи полягає у наступному: ми вдосконалили модель моніторингу та прогнозування ходу бізнес-процесів за рахунок застосування нечіткої когнітивної карти, в якої параметри важливості та пам'яті вузлів та зв'язків забезпечують додаткову гнучкість та можливість узгодження і адаптації в умовах зміни обставин у процесі, що підлягає моніторингу; запропонували метод використання нестійких FCM за рахунок встановлення обмежень значень збудженості вузлів і використання в якості міри збудженості не тільки сталих значень збудженостей вузлів FCM, але і швидкості зростання значень збудженостей як показник тенденцій, що дозволяє відстежувати та прогнозувати перебіг бізнес-процесів.

Ключові слова: моніторинг бізнес-процесів; нечіткі когнітивні карти; графова модель; обчислювальна модель; нестійкі когнітивні карти; база знань.

Шевченко Ігор Васильович – д-р техн. наук, проф. каф. автоматизації та інформаційних систем, Кременчуцький національний університет імені Михайла Остроградського, Кременчук, Україна.

Васильєв Денис Олегович – асп., старш. викл. каф. автоматизації та інформаційних систем, Кременчуцький національний університет імені Михайла Остроградського, Кременчук, Україна.

Притчин Сергій Емільович – д-р техн. наук, проф. каф. автоматизації та інформаційних систем, Кременчуцький національний університет імені Михайла Остроградського, Кременчук, Україна.

Самойлов Андрій Миколайович – старш. викл. каф. автоматизації та інформаційних систем, Кременчуцький національний університет імені Михайла Остроградського, Кременчук, Україна.

Ihor Shevchenko – D.Sc., Professor of Department of Automation and Information Systems, Kremenchuk Mykhailo Ostrogradsky National University, Kremenchuk, Ukraine,
e-mail: ius.shevchenko@gmail.com, ORCID: 0000-0003-3009-8611.

Denys Vasyliev – PhD, Senior Lecturer of Department of Automation and Information Systems, Kremenchuk Mykhailo Ostrogradsky National University, Kremenchuk, Ukraine,
e-mail: mjden710@gmail.com, ORCID: 0000-0002-4330-0359.

Serhii Prytchyn – D.Sc., Professor of Department of Automation and Information Systems, Kremenchuk Mykhailo Ostrogradsky National University, Kremenchuk, Ukraine,
e-mail: pritchinse@gmail.com, ORCID: 0000-0002-9931-1591.

Andrii Samoilov – Senior Lecturer of Department of Automation and Information Systems, Kremenchuk Mykhailo Ostrogradsky National University, Kremenchuk, Ukraine,
e-mail: saman.39@gmail.com, ORCID: 0000-0001-9178-6202.