Systematic assessment of food security by recurrent addition of fuzzy cognitive maps

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Abstract. The results of an analytical review of the problems of modeling the state and evolution of socio-economic systems solved using the mathematical apparatus of matrix analysis of cognitive maps are presented. The difference between classical and fuzzy cognitive maps (FCM) is shown. The problems, strengths and weaknesses of algorithms and tools for assessing the level of food security (FS) based on a fuzzy cognitive approach are considered. The basic groups of concepts and methods for constructing the FCM that provide a fuzzy integral assessment of the PB level are analyzed. A method of recurrent construction of the NCC by successive addition of a set of concepts is proposed. In the process of adding concepts, experts make step-by-step recurrent adjustments to the values of the mutual influence of concepts. Recommendations for justification are presented, using the example of assessing the level of FS, the choice of tools for building the NCC. The solution of the problem of assessing the level of regional FS is illustrated for a set of economic, environmental and organizational concepts. It is shown that for adjusting the parameters generated by the FCM, including to take account of their changes over time require the creation of software tools for fuzzy cognitive modeling, taking into account specific tasks and retrospective information together with simulated system factors.

1. Introduction

The cognitive approach implemented by means of cognitive maps in the form of oriented graphs allows us to successfully solve numerous problems of analyzing and predicting the development of technical and organizational-economic systems for various purposes. Researchers (I. Azhmukhamedov, A. Averkin, V. Borisov, S. Fomenkov, G. Gorelova, O. Zakrzhevskaya, A. Kolodenkova, L. Ginis, R. Isaev, V. Kamaev, A. Kulinich, V. Luferov, U. Orlova, V. Pavlov, N. Paklin, A. Podvisovsky, P. Terelyansky, V. Vasilyev, V. Volkova, S. Yarushev, etc. [10, 12, 16, 19-21]) note the possibility of identifying short- and medium term trends in the evolution of socio-economic systems, including options for their managed development. Experts in the field of cognitive
analysis note the advantages of using fuzzy cognitive maps (FCM) in comparison with classical (iconic) ones [13, 14].

The description of complex socio-economic systems, which also include food security (PB), makes it possible to apply a cognitive approach.

Food security (FS) is a complex socio-economic category, the numerical value of which can be estimated by an integral indicator [6, 11, 12, 15]. There are numerous approaches for constructing such an indicator - analytical and statistical, expert and others. There is no single approach to assessing the FS level, which is due to the complexity of the problem. The latter is due to the significant dimension of the problem of numerical evaluation of FS, the lack of a universal scale for evaluation, insufficient structuring of the problem itself, as well as the lack of all the required numerical data.

To obtain an objectified assessment and identify trends in the FS level, it is possible to use a cognitive approach based on the FCM [3, 5, 7, 8, 10]. At the same time, there are certain limitations to the use of cognitive modeling, due to some uncertainty in the choice of concepts and setting their mutual relations.

In connection with the above, the methodology for constructing the FCM [6], as well as the adaptation and software implementation of the cognitive approach in relation to the numerical assessment of the FS level, is an actual scientific and methodological problem.

2. Materials and methods
The research uses fundamental methods of system analysis - system approach and system theory, cognitive and graph-analytical analysis, theory of algorithms, including the construction of recurrent algorithms.

To describe the FS support system, based on domain analysis, the FCM was constructed in the form of a weighted directed graph, the structure and parameters of which were set by the adjacency matrix \( A(a_{ij}) \) [4, 5]. To form the composition of FCM concepts, a recurrent approach of sequential addition of concepts was proposed. In accordance with the provisions of the theory of algorithms for programming a recurrent algorithm, a recursive loop is implemented that calculates the value of the next member of the sequence.

Software implementation of cognitive modeling was provided using the Strategist computer system developed at Volgograd state technical University [16, 21]. The system has a user-friendly interface that provides interactive construction, visualization, and research of a fuzzy cognitive model.

3. Results and discussion
The national food security Doctrine [18] defines the need to take into account the main groups of factors that characterize the FS level. These groups within the organizational and economic infrastructure include the production of food products, their consumption, food imports, as well as its reserves. Since the FS support system, as a typical socio-economic system, is poorly structured [9], the selection of the necessary and sufficient set of FCM concepts is a separate scientific and methodological task. Such systems are characterized by the fact that their parameters and laws of behavior are described mainly at the qualitative level.

The working hypothesis of the study assumes that changes in the composition and parameters of the system under study can lead to difficult to predict changes in its behavior.

Modeling and managing such systems using traditional approaches based on analytical or statistical descriptions is difficult. This forces us to resort to subjective approaches based on expert information. One of the most effective approaches is cognitive modeling, which allows the decision maker to display an idea of the problem situation in the form of a formal model. This helps to activate the
intellectual processes of analysis and management of the simulated system.

Justification of the choice of the necessary and sufficient set of concepts in the construction of the FCM is a separate scientific and methodological task. To form the composition of FCM concepts, a method of sequential addition of concepts based on a recurrent approach was proposed.

In mathematical analysis, the recurrent approach is a method for calculating a function. Recurrent algorithms define a method for calculating elements of a sequence described using recurrent formulas. The recurrent element of a numeric sequence is calculated as a function of its previous member:

$$X_k = f(X_{k-1})$$

where $$X_0 = a$$ is a preset value.

A more complex case is possible when the subsequent member of the recurrent sequence depends on the two previous ones at once:

$$X_{k+1} = f(X_k, X_{k-1})$$

Depending on (2), $$X_0$$ and $$X_1$$ are preset values, which ensures that the value of the next member of the sequence is calculated.

Let's consider a modified method of cognitive mapping in the part of FCM construction on the example of FS level estimation. In order to support the cognitive modeling procedure, various software tools are used - from the oldest foreign FCMappers [1] to the Russian software complexes "Igla", "Strela", "Strategist" etc. Having approximately equal functionality, they differ mainly in the organization of the interface, as well as technologies for interactive interaction with users.

One of the main problems of cognitive modeling is the complexity of verification of both the developed NCC and the forecast of the evolution of the simulated systems. An almost useful approach to NCC verification is the automated generation of explanations, which rules were used to get the result. For example, the Russian system of cognitive construction of alternatives "Canvas" includes a special block that generates a report on the step-by-step sequence of obtaining the result when explaining the forecast. After verification of the cognitive map, the FCM is corrected, if necessary, for example, using the method based on the analysis of the structural stability of the cognitive map.

The FCMappers cognitive modeling support system [1, 2] makes it easy to set initial values and interaction weights for the concepts considered. The system allows you to visually visualize the structure and parameters of cognitive maps using the Pajek tool.

The Russian software system for cognitive modeling "Igla" provides support for collective work in the construction, research and adjustment of the FCM with the calculation of its system indicators, as well as scenario analysis using the pulse dynamic modeling method.

The analysis showed that there are a number of different tools that provide cognitive modeling using NCC. The choice of the applied tool is determined by the peculiarities of the research problem statement. The variety of simulated systems encourages researchers to create their own software tools [4,5] that take into account the specifics of setting specific research tasks.

Let us extend the recurrent approach in more detail to the procedure for selecting the composition of the concepts of the designed NCC. Using the recurrent approach (2), for $$n$$ considered members of the sequence, we can write

$$X_k = f(X_{k-1}, X_{k-2},..., X_{k-n})$$

where $$X_0 = a$$, ... $$X_n = z$$ - are predefined values.

Let's consider the authors ' proposed application of this approach to constructing fuzzy cognitive maps using the example of FS level estimation.

Previously, a priori ranked list of concepts that experts believe should be taken into account when building a non-clear cognitive map is constructed. Adding the following concept from the constructed list to the fuzzy cognitive map, it is necessary to consistently review the values of weights
corresponding to the new configuration of the modified graph formed by the FCM (Fig. 1 - 3).

The enlarged algorithm for implementing the proposed recurrent approach to the construction of the NCC included blocks for process initialization, checking the completion condition for adding concepts, adding a new concept; expert evaluation of the weights of mutual influence of all concepts, and analysis of the model process due to the introduction of a new concept. The recurrent procedure ends when the stop condition is met. After graph-analytical expert verification using the pulse simulation diagram of the evolution of the system under study, it is possible to conduct a multi-factor scenario analysis.

The basic fuzzy cognitive map, based on the current food security Doctrine of the Russian Federation, included 4 enlarged concepts: agricultural production; food consumption, food inventory management, and food import.

Diagrams of the evolution of the system of the basic system and with the supplemented concept indicator of the integral level FS are shown in Fig. 1, where option a) corresponds to FCM with four groups of basic concepts of the FS support system; option b) additionally takes into account the added concept of the integral indicator of the PB level.

When FCM is supplemented with the new concept "economic infra-structure", which characterizes the financial and economic support of production and processing by the state, the nature of the evolution of the curves changes somewhat (Fig. 2-a). Additional consideration of the concept of "import of pharmacological preparations" leads to another correction of the curves of evolutionary dynamics, which take the form shown in Fig. 2-b.

Thus, by consistently building the FS support systems developed by FCM using the method of recurrent augmentation and enriching them with new concepts, it becomes possible not only to track the impact of new concepts, but also to adjust the parameters of their interaction at each step.

For the effective adjustment of the parameters of the IAC, including the purpose of considering the dynamics of changes in real, rather than a model of time requires the creation of a new means of cognitive modeling program, making serving a specific task and the availability of retrospective information on the totality of the simulated system factors.
Figure 2. Diagrams of the system's evolution taking into account the economic infrastructure: a - state support for rural producers; b - additional accounting for the import of pharmacological preparations.

4. Conclusion
The results of the analytical review showed: (1) The method of selecting and including new concepts in the developed fuzzy cognitive models, based on the intuitive knowledge of experts, requires modification. (2) The method of recurrent addition of FCM includes the preliminary expert construction of a ranked list of concepts that should be taken into account when constructing a cognitive map. Recursively adding the next concept from the ranked list, it is necessary to consistently review and, if necessary, adjust the values of the parameters of the generated FCM corresponding to its new configuration. (3) To adjust the parameters of the generated FCM, including in order to take into account their changes over time, it is necessary to create software tools for fuzzy cognitive modeling that take into account the specifics of specific tasks and the availability of retrospective information.

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