Estimation and forecasting of food security based on fuzzy cognitive approach

A F Rogachev¹,²,*, E N Antamoshkina¹, E V Melikhova¹, T V Pleshenko¹ and I S Belousov¹

¹Volgograd State Agricultural University, 26, Universitetskiy Avenue, Volgograd, 400002, Russian Federation
²Volgograd State Technical University, 28, Lenina Avenue, Volgograd, 400005, Russian Federation

*E-mail: rafr@mail.ru

Abstract. The analysis of a set of groups of factors that form the food security (FS) of the state and its subjects is carried out, and an analytical review of known mathematical methods, as well as fuzzy models for their assessment is performed. The software tools for fuzzy cognitive modeling of the integral level of FS are justified. The key concepts of ensuring and evaluating FS are generalized and numerical estimates of their mutual influence are obtained based on a fuzzy cognitive approach. Along with the main groups of concepts «Production-Consumption-Stocks-Imports» listed in the national «Food security Doctrine», the constructed cognitive model also provides for accounting for additional ones. One of these factors-concepts is «Ecology», by which the authors understand the linguistic meaning of the integral level of the ecological state of the environment. The constructed cognitive map takes into account 11 basic concepts. It is shown that the advantage of the mathematical apparatus of impulse cognitive modeling, selected for research and implemented on a computer, is the possibility of system forecasting the development trends of the systems under study and the results of management decisions. In addition, it becomes possible to identify non-obvious consequences that are difficult to predict by expert method when the number of factors taken into account increases. The results of the analysis, obtained mainly in linguistic terms, are approximate due to the fuzzy nature of the evaluation scales used and reflect only the main trends in the development of the simulated SES. The results obtained allow us to justify a set of measures for the development and implementation of organizational and economic measures for the implementation of the state policy to ensure food and environmental security of the region.

1. Introduction
Fundamental approaches and results of implementation of the state agrarian policy in the sphere of ensuring food security in Russia are considered by A. I. Altukhov [1], V. I. Nazarenko [2]. Certain aspects of food security in the context of the theory and practice of sustainable development of the
Large number of studies are devoted to the analysis of factors that form the food security of the state. In the works of N. Shagayda, E. Gataulina, V. Uzun [5] PB is caused by such factors as resource security (security APK personnel, as well as land and logistical resources), safety of the natural environment and man-made agriculture.

In the works of foreign researchers, the IB state is determined by such factors as determining the offer with the food suppliers that generate demand income and population access to food supplies. The analysis of measures of regulation and support of the agri-food sector of the economy, the characteristics of the organization of the system of food security and control of the safety and quality of food products in the USA, Canada and Europe are presented in the works: R. Capone, H. Bilal, F. Debs [6]. In particular, in the works of M. M. Gill, A. Herforth [7], D. Grace, G. Manuku, V. Hoffmann [8], H. Weikard [9] it is noted that the increase in food production while simultaneously intensifying agriculture has its limits. In the long run, this may lead to an adjustment in food production to a level that will be residual in order to feed the world's population.

The interest of the scientific community in food security problems has contributed to the emergence of a large number of mathematical methods, clear and fuzzy models for their assessment [10-12]. Despite the variety of existing models for assessing food security, many of them are focused on assessing certain aspects of food security, in particular, in the context of import substitution, the Complexity of the analysis lies in the fact that most of these models are not sufficiently formalized, and are largely based on expert assessments.

For example, there are several predictive models (EPACIS, BLS, Aglink) for assessing food security at the macro level. The first of them is based on modeling partial equilibrium in agricultural markets and focuses on foreign trade of the CIS countries. The second model reproduces the goals of market participants and limiting factors in the form of a mathematical programming problem. The third is a recursive dynamic model of partial equilibrium for States and regions of the world.

Simulation forecast models are also used. They allow you to define agri-food policy measures that ensure the achievement of set goals, for example, self-sufficiency of certain types of food at the necessary level. This type of model does little to address food security issues, except when it reveals the prospect of unacceptable food supply imbalances. The variety of types of mathematical models describing PB is mainly focused on statistical data [13, 14], which are not always available and systematized. In this regard, in this study, preference was given to a class of fuzzy cognitive mathematical models that better cope with weakly structured and incomplete information [12,15,16,17].

2. Materials and methods
The problem of modeling and evaluation for the reasonable management of the simulated system using fuzzy cognitive maps (NCC) can be formulated as follows. There are groups of factors that significantly affect the development of the simulated system - control and managed. Changing the managed factors is the immediate goal of managing the system. The control decision determines the choice of a subset of control factors that determines the management strategy. The analytical system APS «Strategist» developed at Volgograd state technical University was chosen as a software tool that implements a cognitive approach to modeling the level of PB [12]. The STRATEGIST system is based on a cognitive approach and provides extensive functionality for building and analyzing cognitive models. The scope of application of APS «Strategist» is weakly structured systems in various socio-economic management areas. The system is intended for instrumental support of managerial decision-making, identification and visual representation of expert knowledge about the subject area, assistance
in studying and analyzing the functioning of complex weakly structured systems. The main functionality of the APS «Strategist» is the variability (in the form of tables, graphs, etc.) of model construction; automated calculation of initial trends; finding mutual influences on the entered statistical data; determining the interconnection of factors, Pareto analysis of detected trends; visualization of models on graphs; modeling of self-and controlled development of the simulated systems, as well as solving the inverse management problem. The import / export subsystem provides import and export of the factor adjacency matrix to a text csv file with a table structure. The factor analysis tool allows you to get a list of factors that affect the selected one, as well as a list of those factors that change under the influence of the selected factor. For clarity, the visualization tool colors the graph by influence levels, which is convenient for visual analysis of the degree of connection between factors. The following types of calculations are implemented: transitive closure of matrices and graphs; identification and calculation of influence chains; calculation and modeling of impulse processes of free and controlled development of the system under study.

3. Results and discussion

The previously analyzed methodological approaches were used in the construction of a fuzzy cognitive map for assessing and predicting the level of FS, characterized by limited numbers of main factors [6, 9]. The Matrix of mutual influence of enlarged groups of factors in the food security system is presented in figure 1. The following selected enlarged groups are indicated in the figure, providing for further decomposition: 1 – economic infrastructure (f1); 2 – food Stocks (f2); 3 – ecology (f3); 4 – imports (f4); 5 – consumption (F5); 6-production (f6); 7 – integrated level of food security (f7).

![Figure 1. Matrix of mutual influence of enlarged groups of factors in the food security system.](image-url)

Fuzzy cognitive maps are intended for formalization, analysis and modeling of problems, weakly structured systems and processes. Fuzzy relational maps provide advanced capabilities for solving these problems under conditions of uncertainty [11].

The analytical system of cognitive modeling «Strategist» was chosen as a software shell for building a cognitive model of PB. It provides flexible configuration for modeling and research of possible scenarios of situations, formation and analysis of various strategies, as well as situational
modeling [12]. APS «Strategist» includes 7 subsystems: expert knowledge extraction; visualization; analysis; modeling; scenario implementation; report generation and import/export.

Building a cognitive model in the APS «Strategist» is possible both visually by editing the generated cognitive map, and by entering a list of concepts entered and expert assessment of the degree of their mutual influence. The visualization subsystem provides mapping of concept factors and their relationships, as well as editing of the resulting cognitive maps. Visualization of the graph analysis of the influence of the simulated concepts, Pareto analysis, graphical representation of the development of the simulated system, ensuring the level of PB are implemented.

Cognitive models built in the «Strategist» environment allow you to change the structure of the simulated systems and the degree of mutual influence of factors-concepts in an interactive mode. Along with the main groups of factors listed in the national «Food security Doctrine» «Production-consumption-stocks-imports», the built model also provides for the accounting of additional factors. One of these factors-concepts is «Ecology», by which we will understand the linguistic meaning of the integral level of the ecological state of the environment.

A generalized cognitive map that takes into account 11 basic groups of factors is shown in figure 2.

![Figure 2. Generalized structure of the cognitive map of interaction of the basic groups of factors of the FS-system.](image)

The evolution of the impulse interaction of factors for the described cognitive map show, that the concept of «Import» is characterized by a positive impact on the concepts of «Reserves» and a negative impact on the concepts of «FS Level», «Economy» and «Ecology». In addition, it is experiencing a positive impact from the concept of «Economy».

Analysis of the results of calculations on the cognitive map (figure 2), showed the following. In relation to the selected factor «Ecology», there is a fluctuating damping change in it, which characterizes the deterioration of the environmental situation against the background of the
development of agricultural production, a decrease in imports and an increase in the integral level of FS.

The scenario subsystem provides a wide range of possibilities for studying various scenarios using the developed PB model. The subsystem allows you to select target and control factors, as well as create groups of observed and excluded indicators for each scenario if they overlap significantly on the chart. After configuring the scenario parameters, you can save the results for each factor in the current scenario. The described subsystem provides opportunities to compare the indicators of alternative scenarios and select the most optimal ones based on target criteria and indicators.

Of particular interest is the solution of the inverse control problem of the simulated system: at what values of control actions and at which vertices of the graph of the cognitive map is it possible to achieve the target values of the set of observed equilibrium values? To solve the inverse problem, it is necessary to conduct a number of numerical experiments, which is almost impossible without using a computer program.

At the same time, the obtained modeling results require logical verification and/or correction with the involvement of experts specializing in the simulated FS subject area. This will make it possible to make science-based decisions when planning crop production, which is the basis for ensuring FS [18, 19].

Thus, despite the wide possibilities of cognitive modeling of dynamic processes of the studied socio-economic systems, additional logical verification of the results obtained with possible adjustment of the structure and numerical values of the incoming parameters is necessary.

4. Conclusion
Analysis of the results of the study based on cognitive modeling, in relation to the problem of assessing the level and forecasting the dynamics of PB, allowed us to formulate the following conclusions and identify the main problems that require further research.

1. The advantage of the mathematical apparatus of the pulse of the cognitive modeling system is the ability to predict development trends of the studied systems and results management decisions, and identifying non-obvious consequences that are difficult to predict by expert method with increasing number of aggregated factors.

2. The results of the analysis, obtained mainly in linguistic terms, are rather approximate due to the fuzzy nature of the scales used and reflect only the main trends in the development of the simulated SES. Forecasts may turn out to be unreliable, in particular, if positive and negative interactions are close, which may be indicated by small values of calculated consonances.

3. The Results obtained allow us to justify a set of measures for the development and implementation of organizational, economic, technical and technological measures for the implementation of the state policy to ensure food and environmental security of the region.

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