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FUZZY COGNITIVE MODELING OF FOOD SECURITY TAKING INTO ACCOUNT IMPORT SUBSTITUTION LEVEL

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Abstract

Theoretical and methodological approaches to modelling the level of food security (FS) based on fuzzy cognitive maps (FCM) are considered. The aim of the study is computer implementation of fuzzy cognitive modelling of food security, taking into account the main groups of factors, including import substitution. The analytical review of scientific publications revealed the following problems that arise when assessing the level of FS: the interdependence of ensuring the required state of FS at different levels of management, which requires taking into account the impact of related sectors of the economy; insufficient completeness of statistical data and not always structured nature of qualitative information about the state of the FS level, making it difficult to mathematically model it using traditional methods. The review analysis of statistical indicators of import substitution in the Russian Federation is carried out. It is shown that it is expedient to take into account the mutual influence of groups of factors: food production and consumption, rational stocks in the conditions of import substitution. The model also takes into account other factors that are significant for the system under consideration. Techniques of impulse modelling using fuzzy cognitive maps are justified. Methods for improving the methods of intellectual cognitive analysis for making forecasts of the level of food security are proposed. The main advantage of impulse fuzzy cognitive modelling is the systematic ability to identify trends in the development of the FS support system when changing the structure and parameters of the socio-economic system modelled by FCM.

Keywords: Food Security, Fuzzy Cognitive Map, Import

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1. Introduction

Features of providing the population with food and food security (FS) in Europe, the United States, and Canada, including state support for agricultural production and the food sector, are studied in the works of such well-known economists as (Capone et al., 2014); (Grace et al., 2015); (Herforth & Gill, 2015); (Weikard, 2016).

1.1. Problems of ensuring and assessing the level of food security

Theoretical and applied aspects of both food security and PB, as well as the implementation of state policy in the field of food security (FS) and the difficulties that arise in this case, including the numerical assessment of its level, are studied by Russian scientists (Altukhov, 2016a; Altukhov, 2016b); (Nazarenko, 2011); (Shagaida, 2016); (Shagaida & Gataulina, 2015); (Shagaida & Uzun, 2015); (Ulezko & Pashina, 2014); (Yarkova & Svetlakov, 2013) and others.

In the context of the implementation of the import substitution policy, a special role is assigned to the assessment of indicators that characterize food security. In the works (Antamoshkina et al., 2016); (Miloserdov, 2017); (Ushachev & Maslov, 2017) an analysis of food security in modern conditions is presented.

The share of food imports in commodity resources for the period 2012-2018, calculated according to (The Regions of Russia. Socio-economic indicators, 2018), is presented in table. 1. The analysis of statistical data of socio-economic development of the Russian Federation showed that the relevance of import substitution in the framework of PB increased in 2014 because of the response of Russia to sanctions by the EU and the USA.

Table 1. Share of food imports in commodity resources, %

Name of food products	2013	2017	2018
Beef, total	59.0	40.9	40.7
Pork, total	31.0	9.6	2.2
Poultry meat, total	12.8	4.4	4.3
Cheeses	48.0	27.3	29.0
Vegetable oils	19.0	14.7	18.1
Powdered milk and cream	60.5	52.6	37.4
Sugar	8.2	3.9	5.1

1.2. Cognitive modelling of the level of food security

An analytical review of publications in the field of problems of assessing FS indicators revealed insufficient methodological foundations, as well as limited tools to support monitoring, assessment and forecasting of the FS level, taking into account various specific factors, including environmental, infrastructure, and import substitution.

There is growing interest in methods for obtaining predictive estimates of FS indicators in order to determine the priority directions of state policy in the field of food security. This means that there are many mathematical methods, models, and algorithms. Most numerical approaches are mainly focused on

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particular FS subsystems, and the subjectivity of the results is often due to their limited formalization and expert nature. The problem of system modelling of food security can be solved by methods of cognitive analysis, including using fuzzy models (Ginis et al., 2016; Rogachev, 2019). Such models are implemented using fuzzy cognitive maps (FCM). Such scientists as (Petrovsky et al., 2013) and others have successfully studied and improved methods of fuzzy cognitive analysis in the Russian Federation.

Actual tasks of FS modeling are justification of the set of modelled factors and their groups, identification and parametrization of relationships between them, justification and software implementation of the matrix pulse modeling procedure, as well as interpretation of the obtained quantitative and qualitative results. These areas determine the relevance of cognitive modeling and the study of various aspects of assessing and predicting the FS level.

2. Problem Statement

We need to develop and implement a computer-based fuzzy cognitive modeling system that allows us to assess the level of food security taking into account the main groups of factors, including the level of import substitution and its interaction with other factors of the socio-economic system of ensuring FS.

3. Research Questions

To solve the indicated problem of fuzzy cognitive modeling, the solution of the following tasks is required.

3.1. Construction of a fuzzy cognitive map, which is a weighted directed graph whose vertices correspond to the selected concepts.

Conducting a preliminary statistical analysis of indicators of the socio-economic system that determine its food security. Substantiation of the composition and nomenclature of factors and their groups that determine the food security of the studied socio-economic system.

3.2. Research and visualization of processes of interaction of factors of the studied socio-economic system, identification of the most significant interactions of factors.

Entering factors and parameters of a cognitive model into a computer system and configuring its parameters for scenario analysis. Getting estimates of the level of food security of the system under study

4. Purpose of the Study

The aim of the study is computer implementation of fuzzy cognitive modeling of the state of food security, taking into account the main groups of factors, including the level of import substitution and its interaction with other factors.

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5. Research Methods

The theoretical foundations and methodology of building FCM based on the system approach are described in the works (Gorelova et al., 2016); (Gorelova et al., 2017); (Ginis et al., 2016); (Klimenko et al., 2018).

5.1. Method of conducting cognitive analysis

The method of conducting cognitive analysis used to assess the level of PB included justification of the system of indicators and / or their groups that ensure the formation of the FCM structure, as well as parametrization of relationships between the concepts of cognitive maps (Rogachev et al., 2020). Fuzzy cognitive modeling was performed directly using the Strategist software package developed at Volgograd technical University. The interface of the mentioned program provides both interactive construction and adjustment of models in the form of FCM, and provides a variety of tools for their research, as well as visual visualization of the results obtained.

5.2. Mathematical apparatus of cognitive modeling

Cognitive modeling of the food security system was performed using a matrix mathematical relationship:

$$x(t) = (I + A + A^2 + \ldots + A^t)x(0), \quad (1)$$

where A - adjacency (incidence) matrix of size n x n, and
t - number of the modeling pulse.

A symptom of instability of the matrix A, when certain factors are to be divergent, is to pre-inform modules of the eigenvalues of matrix elements and sizes made it equal to 1.0. In this case, is recommended the transformation of the original matrix A to sustainable by multiplying the elements in each row of the matrix and the multiplier:

$$Nn = 1/(si + \varepsilon), \quad (2)$$

where si - number of non-zero elements of the i-th column (row);

ε - small positive number.

When constructing the FCM, the results of a preliminary analysis of a set of indicators that form the level of PB and their mutual influence can be used. In case of incomplete or unclear information, expert methods can be used.

6. Findings

In the context of sanctions imposed by a number of foreign countries, Russia's security with food products and certain seed materials has become important (Antamoshkina et al., 2016). Among the food products imported to the territory of the Russian Federation, vegetable and animal oils, various types of dairy and meat products, including canned products, have the largest share, the production and consumption of which should be modelled first.

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6.1. The analysis of statistical data

Preliminary analysis of statistical data (The Regions of Russia. Socio-economic indicators, 2018) showed that in 2018, the share of imported food products in the total volume of the corresponding commodity resources in the Russian Federation reached the following values: beef 41%, milk powder 37%, vegetable oil 18%), cheese 29%. In General, the share of imported food products in retail trade resources in 2019 was 25%, i.e. it increased slightly compared to 24% in 2018. Among the countries that import food products and agricultural raw materials to the Russian Federation, the EU countries, China, Turkey, Brazil, Argentina, Chile, Ecuador are traditionally the leaders, and Belarus is among the CIS countries. Thus, as of December 2019, the share of EU countries accounted for 24.6% in the structure of imported food products, Belarus – 14.1%, China – 5.8%, Turkey – 4.4%, Ecuador – 4.3% (*Indicators that characterize import substitution in Russia*).

In 2018, the volume of production of the main types of food products that are import-substituted in the Russian Federation increased. Beef and chilled veal meat were received more by 10.7%, pork – by 11%, fish – by 11.8%, fruit and berries – by 6.41, while the volume of vegetable production decreased by 11.03% at the end of the year.

The interest of the scientific community in the problems of assessing the level of PB led to the emergence of various mathematical methods and models (Shagaida & Gataulina, 2015). We note the practical lack of approaches for constructing cognitive dynamic FS models based on a fuzzy cognitive approach and their use for solving multi-criteria optimization problems. Methods of in-depth research and forecasting of the situation development are required, including a scenario approach to the formation of saturation and availability of the agricultural and food markets; assessment of the level of threats to the sustainability of food security in Russian regions; design of measures to counteract and mitigate negative consequences, as well as optimization of strategic food reserves and import substitution (Nizhegorodtsev, 2016).

6.2. The study of the integral level of FS using the tools of fuzzy cognitive maps

The interest of the scientific community in the problems of assessing the level of PB led to the emergence of various mathematical methods and models (Shagaida & Gataulina, 2015). We note the practical lack of approaches for constructing cognitive dynamic FS models based on a fuzzy cognitive approach and their use for solving multi-criteria optimization problems. Methods of in-depth research and forecasting of the situation development are required, including a scenario approach to the formation of saturation and availability of the agricultural and food markets; assessment of the level of threats to the sustainability of food security in Russian regions; design of measures to counteract and mitigate negative consequences, as well as optimization of strategic food reserves and import substitution (Nizhegorodtsev, 2016).

In this regard, a scientific hypothesis was formulated for the possibility of an adequate study of the integral level of PB using the tools of fuzzy cognitive maps (FCM). The study justifies the conceptual model of a fuzzy cognitive system for assessing and predicting the level of FS, including taking into account import substitution.

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Let us take a closer look at the application of the theory of fuzzy cognitive maps for analysis, as well as research and management decision - making in the development of intelligent decision support systems in the field of modeling, assessment and food security. Various combinations of cognitive map elements, such as vertices, edges, and their weights, provide a relevant description of the influence of the relationships taken into account.

The main groups of factors of the developed FCM were the production and processing of agricultural products listed in the national Doctrine FS; consumption of products by the population; economic infrastructure (state support, inventory management, standard of living of the population; import) (Figure 1).

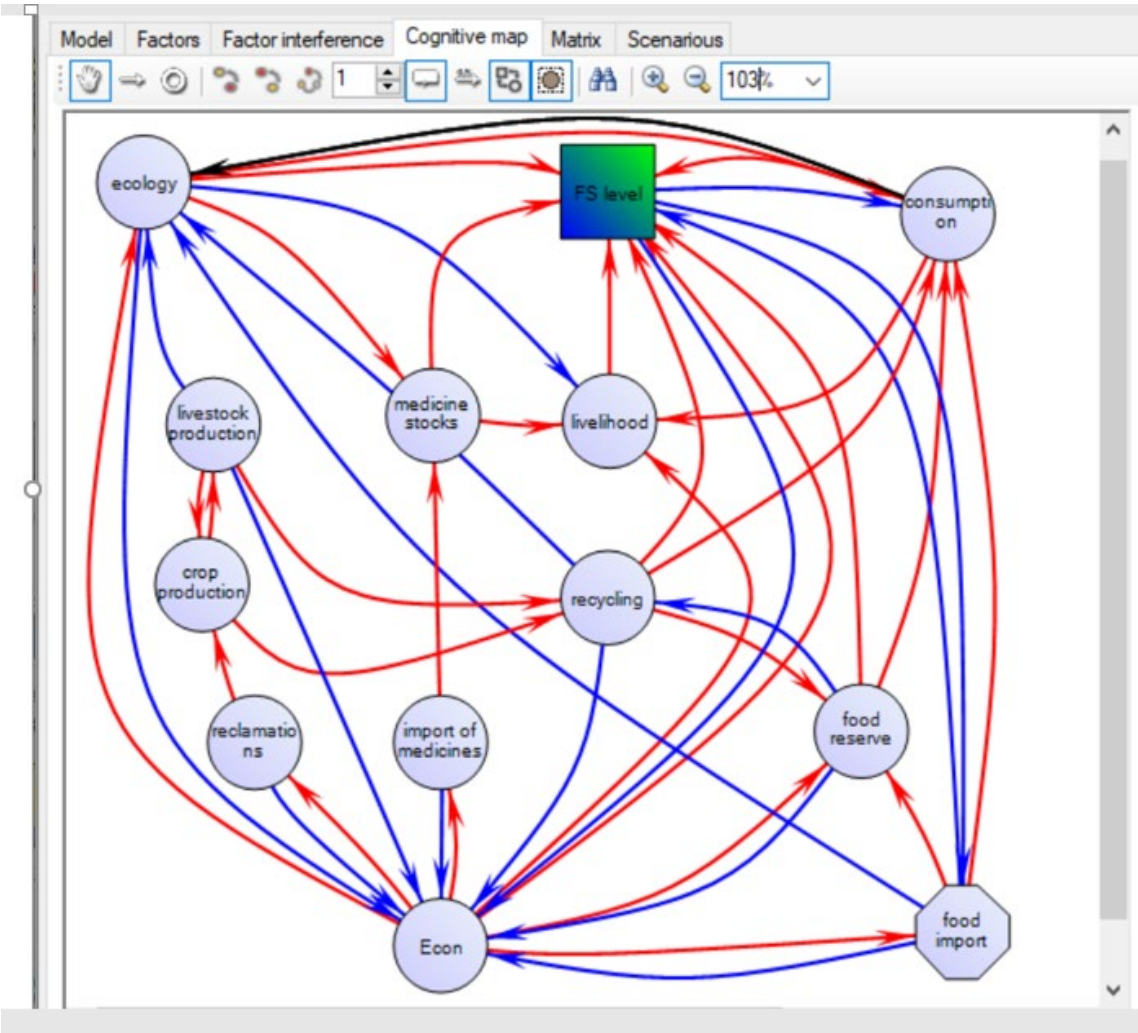

Figure 1. Cognitive FCM of mutual influence of FS level assessment factors

In addition to the above groups of factors, the authors proposed to include additional concepts in the model that have a significant impact on the FS provision. In particular, indicators of import substitution, availability of medicines, as well as ecology, including the reclamation state of land resources, food quality, etc. were additionally introduced into the cognitive model.

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FCM and its corresponding numerical adjacency matrix were constructed to model the PB level. the elements of this matrix are numerical values of mutual relations between concepts that are not clearly expressed by experts.

The numerical implementation of impulse cognitive modeling of self-development of the simulated system is shown in Figure 2. Graphical analysis of the evolution of indicators allowed us to identify the main trends in the numerical values of the concepts of the simulated food security system.

One group of indicators (Processing, Consumption, etc.) steadily monotonously and periodically increases with values observed by about 9 of the analysis epoch. The second group of factors (land Reclamation, Ecology, availability of medicines, etc.) shows a tendency to decrease their initial values. The oscillatory nature of changes in the values of the concepts of the second group also stabilizes by 9 ... 10 epochs of pulse modeling.

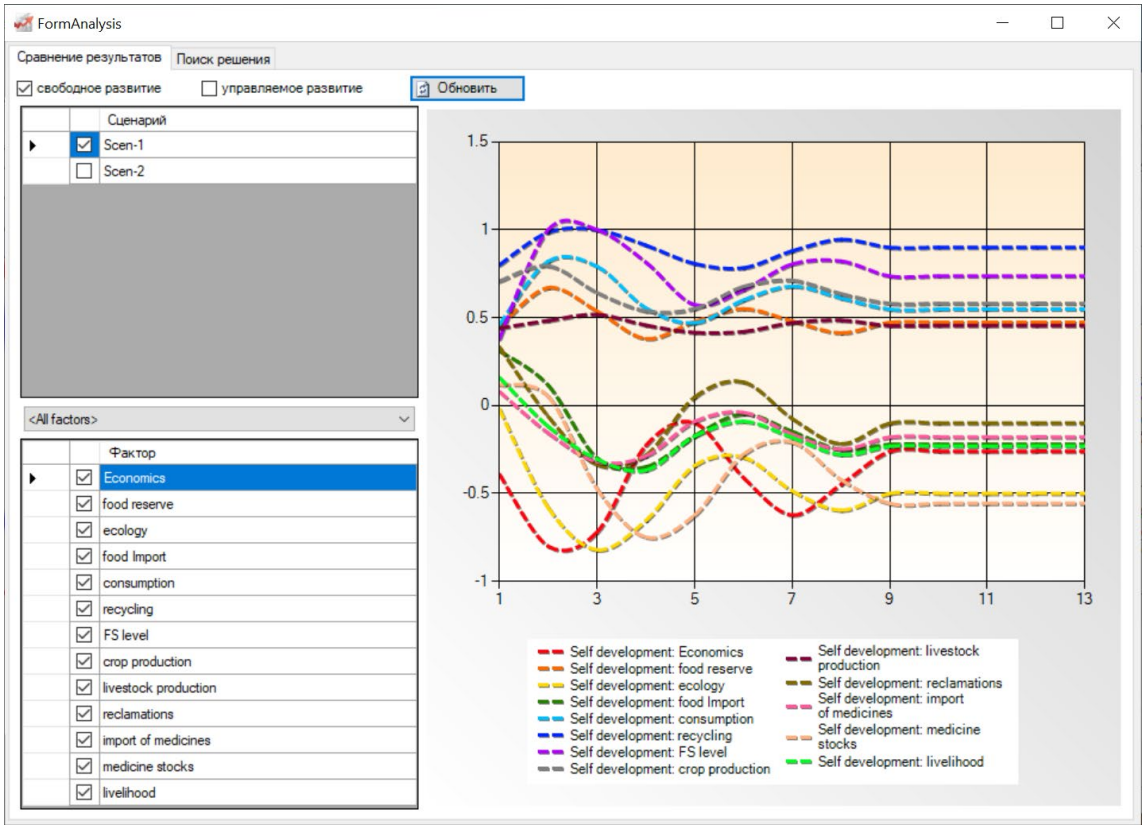

Figure 2. Simulated forecast dynamics of PB indicators

Finally, the combined influence of the concepts of both groups provides a slight fluctuating growth and the integral indicator FS, which fades to the 9th epoch and then its value does not change. Therefore, if the agri-food policy and the influence of exogenous and endogenous factors remain unchanged, it is possible to predict a certain increase in the FS level with its subsequent stabilization.

In order to verify the simulation results, we can consider statistical data on the production of animal products that are critical for the region according to (Antamoshkina et al., 2016).

Let us save only three concepts in the output diagram for clarity (Figure 3) and conduct a graphical analysis of them.

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After the termination of oscillatory processes in the 9th epoch, the value of the concept "livestock products" is stabilized almost at the initial level with a slight excess of its value. This is qualitatively consistent with the data in table 2, where there is a slight increase in the production of beef meat with a constant production of sausage products. We note that according to table 2 vegetable production tends to decrease, which also corresponds to a decrease in the values of the concept "crop Production" in figure 3.

The comparison of qualitative and quantitative results of cognitive modeling with statistical data shows their logical consistency, which is acceptable for fuzzy cognitive modeling. To increase the numerical convergence of the simulation results, it is possible to adjust the values of the weight parameters of the mutual influence of concepts. To do this, it is necessary to present the preliminary results of modeling to the experts and coordinate their judgments on the parameters to be changed.

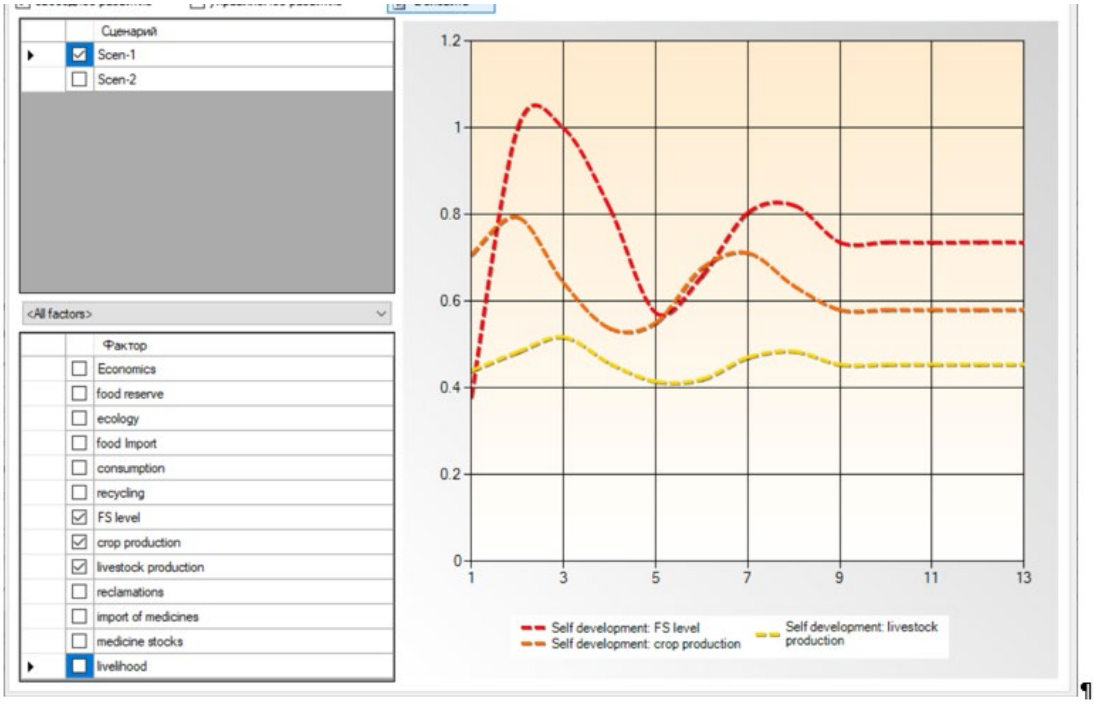

Figure 3. Forecast dynamics of production of interrelated crop and livestock products

The meaning of the concept of "food import" is monotonously decreasing, which makes it possible to predict its tendency to a significant reduction within the framework of the studied infrastructure situation. This justifies the potential for food exports, which is consistent with the state policy of import substitution and ensuring the desired level of FS.

The conducted research using the constructed cognitive model can be used as the basis for scenario analysis when justifying the strategy for the development of the agri-food sector of the economy, which includes both production and processing of agricultural products. Consequently, it is possible to make forecasts for the development of the agro-industrial complex, which is the basis for ensuring food security.

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7. Conclusion

Analysis of the results obtained in the course of fuzzy cognitive modeling and assessment of the predicted level of food safety based on the developed FCM allowed us to formulate the following conclusions.

7.1. An analytical review of scientific publications revealed the following problems that arise when assessing the FS level:

- the interdependence of solving the problem of ensuring the required state of FS at different levels, which requires taking into account external influences from related sectors of the economy;
- different priority of different components that define the target entity of the PB (Shutaeva & Tropanets, 2010);
- insufficient completeness of statistical data and not always structured nature of high-quality information about the state of the FS level, making it difficult to mathematically model it using traditional methods.

7.2. The main advantage of the approach based on impulse cognitive fuzzy modeling is the system ability to identify trends in the development of the studied FS support systems when changing the structure and parameters of the socio-economic system modelled by FCM.

7.3. The problem of ensuring FS is directly related to the implementation of the concept of transition to sustainable socio-economic development. Since the problem of food security is not only not solved on a global scale and continues to worsen in many macro-regions, the application of cognitive approaches to modeling its state can contribute to the development of science-based solutions to ensure FS.

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