

Mathematical modeling of the food-security level using a fuzzy cognitive approach

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Abstract. The article discusses methodological approaches to the problem of assessing the level of food security based on cognitive mathematical modeling. The feasibility of integrated accounting in the context of import substitution primarily of the production and consumption of agricultural products by the population, as well as the volume of their imports and stocks, taking into account rational consumption standards, is substantiated. It is shown that the solution to the problem of ensuring food security is possible using economic and mathematical modeling based on fuzzy production cognitive maps. It is also necessary to develop and improve methods for the intellectual analysis of relevant statistical data to predict the integral level of food security.

1. Introduction

The normative basis for ensuring food security of the Russian Federation is the “Doctrine of Food Security of the Russian Federation”, approved by Decree of the President of the Russian Federation No. 120 of January 30, 2010. The problems, directions and results of the implementation of the state agrarian policy in the field of food safety are described by A.I. Altukhov [1, 2], V.I. Nazarenko [6]. Certain aspects of food security and food security in the context of the theory and practice of sustainable development of the economy of the regions of Russia are presented in the works of A.V. Ulezko, T.M. Yarkova [9, 14]. A number of studies are aimed at identifying and assessing the totality of factors that ensure state safety. In the works of N. Shagaid, E. Gataulina, V. Uzun [11, 18, 13, 10], its level is made dependent on resource security (provision with personnel, material and technical and land resources), as well as the safety of the natural environment and technosphere agricultural production.

In the works of foreign researchers, the state of public health is determined by three factors: available food suppliers (supply), incomes of the population (demand) and access of the population to food supplies. An analysis of the regulation and support of the agri-food sector of the economy, a description of the organization of the food supply system and the control of the safety and quality of food products in Europe, the USA, and Canada are presented in the works: R. Capone H. Captain H. Bilal, F. Debs (Ph. Debs) [16]. In particular, in the works of M. Gill (M. Gill), A. Herforth (A. Herforth) [15], D. Grace (D. Grace), J. Manuku (G. Manuku), V. Hoffmann (V. Hoffmann) [17], H. Weikard (HP Weikard) [19]. Researchers note that the limits of growth in food production in conditions of intensification of agricultural limited, and in the long run will require adjusting the volume of food production to a level sufficient to feed the world's population.

It should be noted that there are no sufficiently strict methods of constructing cognitive dynamic models of food security based on fuzzy cognitive approach and their use for solving multi-criteria optimization problems, including high-dimensional ones. 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 market; assessment of the level of threats to the sustainability of food security of Russian regions; design of countermeasures and mitigation measures, as well as optimization of strategic food stocks.

The methodology of a systematic approach to the construction of intelligent systems, including those based on cognitive maps, has been sufficiently studied [4,5,21,18]. The leading scientific organization in Russia engaged in the development and application of cognitive analysis technology is IPU RAS, unit Sector-51, (Maksimov V.I., Kornoushenko E.K., Kachaev S.V., Grigoryan A.K. and others.). However, the creation of an intellectual cognitive system for automating PB forecasting procedures is complicated by the high dimensionality of the problem, which is determined by the intersectoral nature and a significant number of input quantities and their groups, not all of which are clear and definite, as well as the complex nature of the relationships between them [20]. Solving the formulated problem requires the construction of adequate models based on fuzzy production cognitive maps, improvement and adaptation of existing ones, as well as the creation of new methods for the intellectual analysis of fuzzy cognitive maps for assessing and predicting food security in the context of import substitution.

2. Research Methods

In this review of the FS assessment methodology, the following methods, approaches, and particular analysis techniques were used. To justify the groups of factors and the system of PB indicators, it is advisable to use the expert method of hierarchy analysis. On the basis of the obtained system of indicators, the formation of the structure, relationships and membership functions of fuzzy cognitive maps is carried out. For parameterization of cognitive maps, the construction of the infological and information models is used, which provide a justification of the structure of the relational database of selected statistical indicators. The construction and verification of a family of predictive econometric models is carried out on the basis of particular indicators for food groups. Methods for integrating the resulting econometric models into the cognitive map will be developed based on membership functions and fuzzy logic.

To build, test and debug a specialized software package that implements impulse modeling of analyzed systems, it will be based on incidence matrices corresponding to cognitive maps. A scenario analysis of the level of food security will be carried out using the constructed fuzzy cognitive maps.

3. Results and discussion

Assessing and ensuring an adequate level Food security of the Russian Federation is one of the central tasks in the system of national security, since without a reliable food supply, no country is able to avoid dependence on other states. Three main subcomplexes provide food security: grain, meat and dairy, which account for more than 75% of all production, 80% of production fixed assets and the number of employees.

The large-scale interest in the problems of assessing and predicting the level of PB led to the emergence of a significant number of different approaches, methods and models. Despite their diversity, most of them are focused on the description of individual particular aspects of PB. The lack of objectivity in the analysis results is due to the fact that most of them are not sufficiently formalized, often based on expert estimates.

Currently known predictive mathematical models (EPACIS, BLS, Aglink), allow you to get estimates of the performance indicators at the macro level. The EPACIS model is based on modeling of partial equilibrium in agricultural markets, and great importance is given to foreign trade between CIS countries. The BLS model describes the goals of market players and the constraint conditions of the formulated mathematical programming problem. The third dynamic Aglink model is a recursive description of partial equilibrium, taking into account states and regions. In addition, simulation forecast models are known that make it possible to identify food policy priorities in the agricultural sector. production, ensuring the achievement of preset indicators PB. As them can be self-sufficiency of specific types of food at a given level, their stocks, etc. The described types of models practically do not

contribute to solving the problems of assessing the safety net. An exception is the identification of the occurrence of unacceptable imbalances in the provision of food.

We note the practical lack of approaches for constructing cognitive dynamic models of food security based on a fuzzy cognitive approach and their use for solving multicriteria optimization problems, including high dimensions. Methods of in-depth research and forecasting the development of the situation are required, including a scenario-based approach to the formation of the saturation and accessibility of the agricultural and food market; assessment of the level of threats to the sustainability of food security in the regions of Russia; designing countermeasures and mitigating negative consequences, as well as optimizing strategic food supplies and import substitution [8].

The analysis of the available publications on the subject of systemic modeling of the safety level revealed the need to improve both the theoretical and methodological base, and computer support for monitoring, evaluation and prediction of the level of food safety in the context of import substitution. A methodological approach has also been developed to an integrated assessment of the effectiveness of agri-food policy based on an analysis of its effectiveness, using the Leap - Effectiveness Index of Agrarian and Food Policy obtained by aggregating economic, financial and social indicators, respectively.

$$\text{leap} = \sum(i_e + i_s + i_f), \quad (1)$$

Statistical data for calculating the coefficient of food independence are presented in the table. 1.

Table 1. Level of food self-sufficiency of the Southern Federal District in 2017.

Food	Actual production, thousand tons	the Required volume of food production in accordance with rational norms	Cc
Eggs, million pieces	5573.1	4271.4	1.30
Meat	993.8	1199.3	0.82
Milk	3578.2	5339.2	0.67
Potatoes	2109.3	1478.5	1.42
Vegetables	3892.5	2299.9	1.69

It should be noted that the situation with the consumption of milk and dairy products continues to be unsatisfactory. In particular, the volume of consumption of milk and dairy products in the southern Federal district was lower than the average volume of consumption in Russia as a whole by 15 kg per year. The actual consumption of eggs in the southern Federal district in 2017 averaged 306 PCs, according to this indicator, the region exceeded the average level of consumption in Russia by 9.7%.

The established rational rate of sugar consumption of 24 kg per year, the population of the southern Federal district in 2017 exceeded almost 2 times, the average volume of consumption was 42 kg, which exceeded the average in Russia-39 kg (table. 2).

Such a significant excess of sugar consumption, revealed in comparison with the recommended rational norms of consumption [22] indicates an imbalance in the food diet of the population of the southern Federal district. The volume of consumption of vegetable oil in 2017 by the population of the southern Federal district amounted to 14.6 kg, which slightly exceeded the established rational level of consumption-12 kg. using the obtained values (CFP), the average value is determined and the indicator of economic efficiency of agricultural policy (i_e) is calculated, the value of which was 0.2.

The interest on the part of the scientific community in food safety issues contributed to the emergence of a fairly large number of assessment methods and models. Despite the variety of existing models for assessing food security, many of them are focused on assessing specific aspects of food security. The complexity of the analysis lies in the fact that most of these models are not sufficiently formalized, and rely heavily on expert estimates.

Table 2. Food consumption in the Southern Federal district (per capita, kg/year).

Subject of the Russian Federation and level of consumption	Bread products	Meat products	Dairy products	Eggs, PCs	Sugar vegetable	Oil
Russian Federation	117	75	231	279	39	13.9
SFD	119	75	216	306	42	14.6
Rational norms of consumption [22]	96	73	325	260	24	12
$K_{f.c}$	1.23		0.66	1.18	1.75	1.21

The definition of the indicator (is) showed that the population with incomes below the subsistence minimum in the southern Federal district in 2017 amounted to 16.1% [12, p. 228]. The value (is) depending on the analyzed parameter will be 0.2.

The share of food expenses in the structure of household expenses of the southern Federal district in 2017 amounted to 37.9%, the figure for Russia as a whole is lower-34.3%. In a number of regions of the southern Federal district there is a rather unfavorable situation in terms of the structure of consumer spending. In the Republic of Crimea and the city of Sevastopol, about half of household spending is on food. Thus, in the Republic of Crimea in 2017, the share of food costs decreased by 5.4% compared to the level of spending in 2016 and amounted to 46.2%, in the city of Sevastopol, food costs amounted to 52.7% of the total cost of consumers [23, p. 236]. The value (is) was 0.1. The Gini coefficient in 2017 was equal to 0.362 [23, p. 220]. The value (is) depending on the K_j is – 0.1.

However, there are no recommendations for constructing cognitive dynamic models of food security based on a fuzzy cognitive approach and their use for solving multicriteria optimization problems, including high dimensions. Methods of in-depth research and forecasting the development of the situation are required, including a scenario-based approach to the formation of the saturation and accessibility of the agricultural and food market; assessment of the level of threats to the sustainability of food security in the regions of Russia; designing countermeasures and mitigating negative consequences, as well as optimizing strategic food supplies and import substitution [10].

The analysis of the available publications on the subject of the project revealed the need to improve both the theoretical and methodological base and computer support for the monitoring, evaluation and forecasting of the level of food security in the context of import substitution. This made it possible to formulate a scientific hypothesis consisting in the possibility of adequate assessment and study of the integral level of BP using cognitive maps. Cognitive maps provide modeling of the main areas of formation of the level of food security with the receipt of an integral indicator. When constructing cognitive maps, the results of the analysis of a system of groups of factors and indicators that form the level of food security are used.

A fuzzy cognitive map (FCM) is usually understood as a cause and effect network $G = (C, W)$, where C is a set of concepts, W - is a set of connections between concepts $w(c_i, c_j) \in W \rightarrow [-1; 1]$. Based on the constructed fuzzy cognitive map, matrices of interaction of concepts on each other are formed, after which the behavior and stability of the constructed map are investigated. A comparison of the quality of models based on clear and fuzzy cognitive maps is presented in the table.

The mathematical apparatus of cognitive modeling includes:

1. Self-development of the situation

The dynamics of the free motion of the state $x(t)$ of the model is described by the equation:

$$x(t) = (I + A + A^2 + \dots + A^n)x(o) \quad (2)$$

where I is the identity matrix;

A is an adjacency matrix of size $n \times n$;
 $x(0)$ - initial conditions.

2. Modeling the controlled development of the system:

$$v(t + 1) = P(0) \cdot A^n \tag{3}$$

where $P(0)$ is the momentum;
 A is an adjacency matrix of size $n \times n$.

Possible modes of using impulse cognitive analysis are presented in Fig. 1. According to dependencies (1), (2), the system indicators of the fuzzy card are calculated.

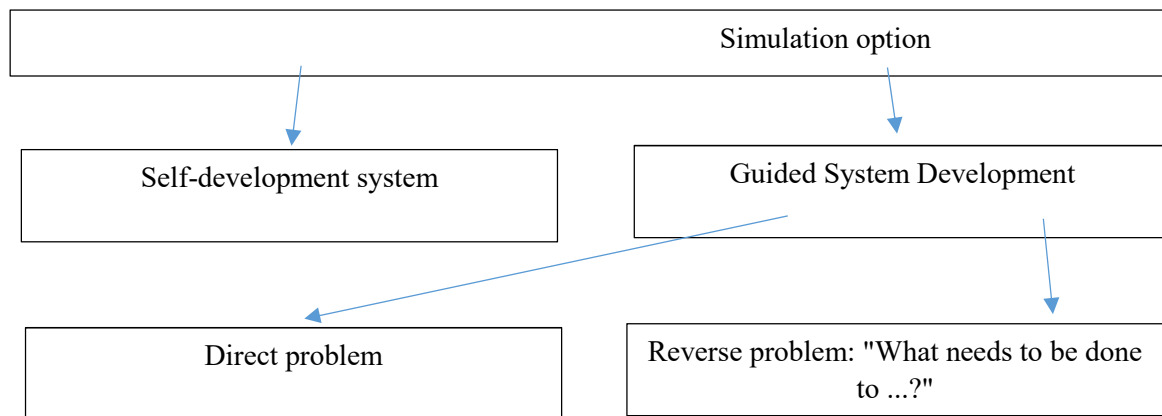


Figure 1. Modes of modeling the development of the situation.

Such indicators are, for example, the consonances and dissonances of the influence of PB concepts on each other, the calculation of which is based on a comparison of the contours formed from the concepts of the map according to the criterion of correspondence, balance and power of influence.

One of the effective FCC training algorithms is the Habbian differential algorithm or more efficient methods, for example, a balanced differential algorithm.

To support numerical research and scenario analysis using developed cognitive maps, a software package is required. Such a set of programs should include a computer program, a knowledge base for constructing the functions of belonging of factors and a database of statistical data for research, using an intelligent system for assessing and predicting the integral level of FS.

Table 3. Qualitative comparison of positive and negative aspects of models based on clear and fuzzy cognitive maps.

Clear Cognitive Map		Fuzzy Cognitive Map	
+	-	+	-
Easy to compose and simulate a pulsed process		Better “recovery” of expert knowledge	The complexity of compiling and modeling a pulsed process
Short simulation time	Using clear ratings	Using fuzzy ratings	Difficulty setting cognitive map
	The output of evaluations of correspondence from the interval [0; 1]		Not 100% fuzzy, there are restrictions on the used accessory functions in fuzzy products; defuzzification of intermediate fuzzy concept evaluations used

Thus, the analysis and results obtained in the research process, allows us to justify the concept of creating intelligent systems for assessing and forecasting the level of food security of the state and individual

regions on the basis of systematic and cognitive approach, in particular in terms of sanctions and import substitution.

4. Conclusion

The study substantiates the concept of creating an intelligent system for multi-criteria assessment and prediction of the state of the state in conditions of import substitution based on a fuzzy cognitive approach.

To build it you need:

- substantiation of the theoretical and methodological basis of an integrated assessment of the level of food security in the conditions of import substitution;
- development of a system of indicators and a methodology for constructing unclear production cognitive maps for assessing the forecast for ensuring the level of food security, taking into account the areas of production, consumption, reservation and import;
- development of methods and construction of membership functions for food safety factors considered in production cognitive maps;
- building a system of fuzzy cognitive maps to assess the level of food security of subjects of various levels;
- modeling of self-development and controlled development of the food security system using the obtained cognitive maps for subjects of various levels;
- development of a software package for monitoring, assessing the level of food security and predicting its dynamics.

The fulfillment of these subproblems will make it possible to solve the problem of an objective integrated assessment of the level of food security based on the intellectual cognitive system, as well as to assess the dynamics of its changes taking into account management by state bodies.

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