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Cognitive Model of Regional Agricultural Sector

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Abstract. In this article, the authors suggest complementing the strategical management methods for the agricultural sector of the region with cognitive modeling technologies. In particular, they developed an integrated cognitive management model comprising two identifying models: the cognitive model of the research subject (the regional agricultural sector) and the cognitive model of the environment (the static model of the region's agricultural sector), as well as the dynamic cognitive model that allows for the modeling of controlling actions in the sector and assess the results of management decisions. The practical significance of the research lies in the formalization of the management decision-making to implement the model when creating a digital twin of the industry on the digital communications platform for the region's agricultural sector. The model is versatile because it can be used to model strategic control actions in any of the regions of Russia. One of the drawbacks of this model is the use of the expert approach because of its subjectivity.

1. Introduction

Modern information technologies provide additional opportunities to improve the quality of management decisions in sectoral economies. One of such solutions is a digital platform for the region's agricultural industry. The development of such a solution as a means of propagating the digital infrastructure of the sector and the region was justified in [1-5], and the general concept was presented in [6, 7].

Considering that the digital communications platform of the agricultural sector shall become a digital twin for the industry, it is necessary to describe in detail the object domain, the interaction model for the economic entities within the sector, and the management model of the agricultural sector, which will later be implemented in a digital environment, beforehand. The results of this research will be used to formulate the design specifications for IT specialists.

Previously, the authors described the object domain of the region's agricultural sector as an ontological model. At this stage of the research, they are developing the strategic management model for the region's agricultural sector.

Taking into account the complexity of the region's agricultural sector as an economic system and the multidimensionality of the processes in it, we deem it feasible to use cognitive modeling technologies with fuzzy cognitive maps. Besides, this work relies on analysis, synthesis, and decomposition, as well as the systemic and synergetic approaches and the elements of cybernetics.

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We suggest constructing an integrated cognitive model of the agricultural sector that would combine the cognitive model of the object and the static and dynamic models of the agricultural sector environment. Cognitive modeling is based on the findings of Russian and foreign scientists presented in [8-16].

2. Constructing the cognitive model of the research subject

This approach can be used to form the cognitive model and take management decisions in three stages (Figure 1).

Review the specific features of every stage.

The cognitive model of the subject reflects sector entities. The ontological model of the region's agricultural sector we constructed previously helped us identify the concepts that are essentially the key entity categories. The authors of the article [17] presented a general concept of the cognitive model of the agricultural sector and described a two-level cognitive model using mathematical tools.

In this research work, we suggest indicator groups reflect the efficiency of model concept activities (Table 1) and key indicators suitable for the agricultural sector of any region (Table 2). We also developed a cognitive map to reflect the impacts of concept activities on the results of the whole (Figure 2). The agricultural sector is denoted as PPP in the figure.

Notation	Sector entity group	Key indicators
P1	Agricultural raw material producers	Sales revenue, production profitability,
		tax load, crop yield, productivity
P2	Agricultural raw material processers	Sales revenue, production profitability,
		tax load, labor productivity
P3	Resource suppliers	Prices, tariffs
P4	Agricultural product sellers	Prices, sales revenue, sales margin
P5	Agricultural product consumers	Demand
P6	Sectoral state authorities	Across the aspects of agricultural
		support measures in the region

Table 1. The notation of sector entity groups and identification of their key indicators.

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Stage 1. The cognitive model of the subject 1.1 Setting the goal of forming the cognitive model of the agricultural sector 1.2 Selecting target indicators for the regions agricultural sector 1.3 Forming the set of region's agricultural sector entities 1.4 Establishing the set of key indicators for each of the sectoral entity categories 1.5 Constructing the cognitive map of entity indicators' impact on the sectoral indicators Stage 2. The static cognitive model of the region's agricultural sector environment 2.1 Establishing the group of experts 2.2 Selecting the management factors for the external and internal environment 2.3 Constructing the "tree" of factors 2.4 Expert assessment of factor significance 2.5 Constructing the oriented graph 2.6 Expert assessment of the impact efficiency for management factors 2.7 Calculating the integral evaluation of the current state of the region's agricultural sector Stage 3. The dynamic cognitive model of the region's agricultural sector environment 3.1 Identifying the target values of the key agricultural sector indicators 3.2 Developing a list of actions targeting the internal and external management factors depending on their significance for the key indicator 3.3 Setting the sequence and assessing the efficiency of management factor impacts over time 3.4 Calculating the integral evaluation of the future state of the region's agricultural sector 3.5 Result analysis 3.6 Developing several strategic management scenarios for the region's agricultural sector 3.7 Selecting and implementing the most suitable scenario

Figure 1. Integrated cognitive management model for the agricultural sector of the region

Notation	Key indicators of the region's agricultural sector
G1	Agricultural production output across all categories of farms in rubles
G2	The profitability of agricultural companies in %
G3	The share of deep processing of agricultural raw materials at the companies
	located in the region in %
G4	The share of high-efficiency workplaces in %

Table 2. Key	indicators	of the ag	ricultural	sector of	the region.
					4 /

Some of the key indicators can be expanded, e.g. the key development indicators of the agricultural sectors of the Republic of Tatarstan and the Republic of Bashkortostan up to 2030 [18, 19].



Figure 2. The cognitive map of concept activity impacts on the key indicators of the sector.

3. Constructing the static cognitive model of the region's agricultural sector environment

To construct the static cognitive model of the region's agricultural sector environment, we must first set up a group of sector experts.

The cognitive model of the environment reflects the current state of the industry. It is an oriented graph whose nodes are the factors impacting the state of the system, while its weighted links are causal ones. Their "weights" reflect the efficiency of management factor impacts on the target factors. Directed links have 'minus' or 'plus' tags depending on whether the expert considers the impact negative or positive.

Environmental factors are closely connected with sectoral entities. SWOT and PEST analyses of the region's agricultural sector can be used to identify the management factors of the agricultural sector environment. Table 3 shows the management factors of the internal environment for the agricultural sector, and Table 4 shows the management factors of the external environment of the agricultural sector.

Table 3. The management f	actors of the internal	environment of th	he region's a	gricultural sector.
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Notation	Internal factors of the region's agricultural sector
I1	Competitive ability of plant products
I2	Competitive ability of animal products
I3	Agricultural product prime cost
I4	Agricultural raw material processing share
I5	Procurement prices of processing companies

I6 Intr	asectoral cooperation
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- I7 Cross-sectoral cooperation
- I8 The share of vertically integrated companies
- I9 The insurance system in the sector
- I10 The system of government procurement interventions
- I11 The availability of skilled personnel
- I12 Average nominal wage in the sector
- I13 Credit resource availability
- I14 The availability of equipment and technologies for agricultural companies
- I15 The condition of the agricultural machinery fleet and the key assets of agricultural companies
- I16 Soil-improvement system development
- I17 The attractiveness of social infrastructure in the rural areas of the region (the quality, quantity, and availability of housing, the state of roads and transport infrastructure, the availability of gas, water, and heat supply, the availability of healthcare, education, and entertainment)
- I18 Regional state support programs for agricultural producers
- I19 The use of current international advances in agriculture.
- I20 The use of Industry 4.0 technologies
- I21 The availability of high-quality seed stock for crop farming
- I22 The availability of highly productive breeding stock for ranching
- I23 Labor productivity
- I24 The availability of innovative technologies and automation means for industrial and household farms in the region.

Table 4. The management factors of the external environment of the region's agricultural sector.

Notation	External factors of the region's agricultural sector
E1	Region's natural resources
E2	Agriculture and climate conditions
E3	Farmland quality
E4	Farmland availability
E5	Water availability
E6	Export potential (abroad and to other regions)
E7	Geographic location (closeness to large consumer markets)
E8	Region's attractiveness for tourists, including agri-tourism and eco-tourism
E9	The demographic situation in the region
E10	Food embargo/agricultural products import ban
E11	The promotion of eco-friendly farmers' products
E12	Convertible currency exchange rates (US dollar, euro)
E13	The share of chain retailers in the regional food market
E14	The quality of life in the region
E15	The investment attractiveness of the region
E16	The digital infrastructure in the region
E17	The logistics infrastructure of the region (roads, transport, warehouses)
E18	Research facilities in the region's agricultural sector
E19	The ability to attract investment from the federal budget
E20	The ability to attract investment from the regional budget
E21	Inflation levels

The authors developed a cognitive map for the region's agricultural sector. It is an oriented graph (G, I, E, L) where $G \in \{g_m\}$ is a set of key sector indicators; $I \in \{i_k\}$ is a set of management factors for the internal environment of the sector; $E \in \{e_n\}$ is a set of managing factors for the external environment of the sector; L is a set of causal links determining the character and efficiency of factors' impacts among each other and the key indicators of the agricultural sector.

Figure 3 shows a fragment of the cognitive map of the sector's environment reflecting the relations between the key factors of the region's agricultural sector and management factors of the sector's internal environment.



Figure 3. A fragment of the cognitive map of the region's agricultural sector.

The oriented graph shall be complemented by the sector's external environment factors. Thus, we build a "tree" of factors. Its top-level contains the key indicators of the sector, the second level contains first-order factors, the third level contains second-level factors, etc. For instance, first-order factors for G1 include I1, I2, I6, I7, I8, I10, I23, while second-order factors include I9, I11, I12, I21, I22. Experts are suggested to assign significance to each of the factors so that the sum of significance coefficients of the factors of the same level equaled one. After this, experts assess the efficiency of management factor impacts on the key sector indicators in the current period.

In fuzzy cognitive maps, the impact efficiency between factors is determined using verbal assessments. To convert verbal assessments into quantitative ones, we suggest using the data from Table 5. Thus, the experts should use this chart when assessing the efficiency of factor impacts.

Verbal assessment	Quantitative assessment (per module)
Very low/very bad/very poor	0.1
Low/bad/poor	0.3
Average/moderate	0.5
High/good/strong	0.7
Very high/very good/very strong	0.9

Table 5. The conversion table for verbal and quantitative assessments.

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The integral assessment of the current state of the agricultural sector environment in the region is calculated using the key sector indicators and taking into account the significance and efficiency of the impacts of all the management factors.

4. Constructing the dynamic cognitive model of the region's agricultural sector environment

The static cognitive model of the region's agricultural sector becomes dynamic when experts begin modeling the strategic development of the sector using the results of the integral assessment of the current state of the region's agricultural sector. Dynamic changes are imitated by applying consecutive impulse impacts on the factors of the internal and external environment and wave modeling for these sector indicator impacts at discrete periods (years). The Impulse Process Rule was described in [20]. The value of the key indicator at every step (year) is calculated as the sum of the indicator value during the previous moment (year) and the impacts of the management factors at the current stage. At the same time, we consider the significance of the management factors and their impact efficiency. The goal of dynamic modeling is to help the system transit from the current state to the target state of the region's agricultural sector, which can be described using the following formula:

$$F = \left(G^f, V(G^f)\right),\tag{1}$$

where G^f is a set of key indicator values comprising subset $G (G^f \in G)$;

 $V(G^{f})$ is the assessment vector for the key indicator dynamics determining their desired changes. The changes may take place in the interval [-1; +1] – from a significant reduction to a significant increase of G during step t.

At this stage, it is necessary to consider the results of constructing the cognitive map of concept activity impacts on the key indicators of the sector as well.

Steps 3.2, 3.3, 3.4 of the dynamic modeling of the region's agricultural sector environment described in Figure 1 make up a complete cycle. If the expert group is not satisfied with the result of step 3.4, they can return to step 3.2 and develop a new set of actions. They can also adjust the duration of the process during step 3.3. As a result, the expert group models the best management decision scenario that is then approved for implementation. Thus, the dynamic model allows for the modeling of controlled sector development.

5. Conclusions

The integrated cognitive management model for the agricultural sector of the region suggested by the authors is novel in some ways:

1) the integrated cognitive model combines three models: the cognitive model of the subject (region's agricultural sector), the static model of the agricultural sector environment, and the dynamic model of the agricultural sector environment, which helps describe the object domain of the sector, shift from the quality description of management factors of the external and internal environment to the quantitative assessment of the sector state in the current period, and develop a set of activities to transit the system into the desired state with the opportunity to optimize the duration of the process and calculate the preliminary result;

2) the suggested cognitive model of the subject reflects the structure of the sector and the set of indicators for each of the entity (concept) categories whose critical values may be tracked in the future and signal that the system is unbalanced. The two-level hierarchy of the cognitive model of the subject allows for its adaptation to the information environment of the digital platform;

3) the integrated cognitive management model for the agricultural sector of the region is formalized to the fullest to be implemented in the digital environment as a technology that would facilitate the implementation of management decisions in the sector.

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