sciendo INTERNATIONAL JOURNAL ON SMART SENSING AND INTELLIGENT SYSTEMS

Special Issue | DOI: 10.2478/ijssis-2024-0003 Issue 1 | Vol. 17 (2024)

Cognitive Modeling as a Forecasting Tool

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Received for publication: June 14, 2023.

Abstract

Under the current geopolitical conditions and the economic sanctions imposed on Russia, there is an objective need to formulate a strategic development plan for the economy as a whole and for specific sectors of the economy. Various methods and tools can be used for strategic planning. One of the methods of strategic planning is the program-targeted method of planning, which has proved to be an effective method of foresight. It is possible to speak about failures of planning activities, but these failures were related not only to shortcomings and application of science-based planning methods but also to the efficiency of the managerial apparatus, which took decisions. It should be noted that it was in the period when science-based planning methods were applied that our country managed to form and develop industrial production in various sectors, and the issue of import substitution did not arise then, as all the stages of the product life cycle were represented at all the enterprises. Currently, the country is facing the problem of strategic development in the context of the imposed economic sanctions. The volume of sanctions is increasing day by day and one can only speculate on the future restrictions imposed. Therefore, there is a need to forecast activities at the level of the whole country, individual industries, and enterprises. One such method is cognitive modeling based on fuzzy logic. This approach involves the use of cognitive principles and methods to understand the behavior of individuals in the system, as well as the interactions and feedback loops between the various components. The purpose of this paper is to retrospectively analyze the application of the cognitive method to modeling. Information systems that have been developed in our country to implement the tasks of cognitive modeling are reviewed, and an assessment of existing software products is made. Also, theoretical materials on cognitive approach in modeling are presented in order to understand the application of this toolkit for modeling socioeconomic systems using elements of fuzzy logic.

Keywords

Cognitive modeling, fuzzy logic, forecasting, long-term planning, neuroimaging

I. Introduction

The purpose of this study is to provide research and history of cognitive research. During the study, it is planned to consider the works of leading Russian (Soviet) and foreign scientists in the field of theory, methodology, and practice of cognitive modeling. There will also be research into the capabilities of software products developed for cognitive modeling and the possibility of their application. Analysis of

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software products has not previously been presented in scientific publications. This article presents the results of a study that allows us to evaluate the possibilities of using cognitive modeling and it is potential.

Cognitive modeling is a scientific discipline that studies how the human brain processes information and creates internal representations of the world around us. It is based on the assumption that the work of the brain can be represented in the form of a computer model that can simulate its functioning.

Cognitive modeling itself is a branch of artificial intelligence, the purpose of which is to simulate human thinking and decision-making processes. In economics, cognitive modeling is used to understand and predict the behavior of complex economic systems. At the domestic level, the cognitive approach has found application in the management of various socioeconomic systems, such as healthcare, education, and business. For example, in healthcare, cognitive interventions such as cognitive behavioral therapy have been used to treat mental disorders. In education, the cognitive approach has been used to develop learning strategies that are better aligned with how people process and store information. In business, the cognitive approach is used to improve decision-making processes and optimize the effectiveness of the organization.

At the international level, the cognitive approach is applied in a similar way, with some countries paying more attention to its use in the management of socioeconomic systems. For example, in the Netherlands, the cognitive approach was used in the management of transport systems, where it was used to improve traffic flow and reduce accidents. In Japan, the cognitive approach has been applied in the management of disaster response systems, where it has been used to improve decision-making and communication between emergency services.

a. Analysis of the results of previous work

The history of cognitive modeling begins with the development of cybernetics in the 1940s. In 1956, John McCarthy, Marvin Minsky, Nat Rochester, and Claude Shannon founded the Summer Research Conference on Artificial Intelligence, which became the starting point for the development of cognitive science (Solomonoff, 1985; Moor, 2006; Ronald, 2011). In the 1960s, the theory of symbolic information processing emerged, which suggested that we can understand cognitive processes by breaking them down into simpler elements.

In the 1970s and 1980s, cognitive modeling became one of the main trends in cognitive science. Researchers have developed computer models that mimic the processes of perception, memory, and thinking. Such models allowed researchers to test their hypotheses about how the human brain works and identify contradictions between theory and reality.

Today cognitive modeling continues its development with the help of modern methods of computer modeling and statistical analysis. It has been successfully applied in many fields, including psychology, neuroscience, philosophy, artificial intelligence, and robotics.

In Russia, cognitive modeling in applications to complex systems began in the 1990s thanks to scientists of the IPU RAS (Abramova & Avdeeva, 2008; Kulba et al., 2002; Maksimov, 2001). From these works, research has grown in many universities of the Russian Federation, including ITA SFU. The experience gained during this time has shown that cognitive modeling is effective for socioeconomic, environmental, geopolitical, sociotechnical, and other complex systems. The results of some studies have been published in the works (Gorelova & Kalinichenko, 2018; Gorelova & Pankratova, 2015; Kalinichenko, 2019). In modern publications, the author explores issues of cognitive deliberation of socioeconomic, including regional systems (Gorelova, 2022; Pankratova et al., 2022; Gorelova et al., 2021; Firsova et al., 2023). An analysis of this type of journal International Journal of Cognitive Research in Science, Engineering and Education from the period 2019 to 2023 showed a lack of articles on cognitive models. Only one article is devoted to cognitive models in text analysis.

Основная задача при моделировании социально-экономических объектов заключается в построении модели, позволяющей прогнозировать реакцию изменения экономики региона или страны.

Психология, кибернетика, философия, лингвистика, теория систем, нечеткая логика, теория графов – вот приблизительный перечень наук, определивших направление современных когнитивных исследований.

In our opinion, the country's industrial planning system should be formed at the country level and then "descend" to the regional level and the enterprise level. This planning system should be based on accurate quantitative indicators. Cognitive modeling can help in planning quantitative indicators of industrial production, which allows taking into account target, disturbing, and regulatory factors.

The term “cognitive maps” was first proposed in 1948 by the American psychologist Tolman in his work “Cognitive maps in rats and humans” (Tolman, 1948). In the development of this cognitive methodology are the main works of Casti, Atkin, and Roberts (Atkin, 1997; Casti, 1979; Axelrod, 1976; Roberts, 1978). According to these works, a cognitive map is a diagram that visually displays the representation of a subject (researcher, expert, and decision-maker) about the system of causal relationships between concepts (objects, entities, concepts, factors, interacting systems and their blocks) within a particular subject area or direction of cognitive science. The creation of such a map is carried out with a specific purpose. Cognitive modeling allows you to make forecasts for the development of the systems under study, determine the directions of development, and determine how the cause vertices influence the effect vertices in the cognitive model. This allows us to make forecasts for the development of the systems under study under various scenarios (Naidenova et al., 2020).

II. Methods and Materials of the Study

A cognitive map is a knowledge structure that is mathematically described by a sign-oriented graph G. Cognitive structuring, or cognitive mapping, refers to the process of identifying the target and undesirable states of the control object, as well as the most important management factors and environmental factors that can affect the transition of the object to these states. In addition, cognitive structuring involves establishing qualitative and quantitative relationships between factors, taking into account their interaction with each other.

Cognitive modeling of a large system can provide insight into the factors influencing the behavior of complex systems and can help identify opportunities for intervention or improvement. For example, understanding cognitive biases in decision-making processes can help decision-makers develop more effective development strategies.

One of the approaches to cognitive modeling of the history of a large system is to create computational models that simulate the behavior of the system and its various components. These models may include cognitive principles such as decision-making, learning, and perception to better understand the factors that influenced the development of the system and how it may evolve in the future.

Another approach is to use historical and statistical data and their analysis to identify patterns and trends in the system. This may include studying the behavior of individual elements in the system, as well as interactions and feedback loops between various components.

In decision support systems (DSS), cognitive modeling is used to analyze and optimize decision-making processes, as well as to develop more effective decision-making strategies.

Cognitive modeling allows to:

Assess the situation;

Analyze the mutual influence of existing factors;

Identify trends in the development of the situation;

Develop a strategy for the development of the situation;

Determine possible variants of the situation development.

The position of describing the system in terms of entropy turns out to be the most suitable for the cognitive approach to modeling complex socioeconomic systems. Thus, it is possible to understand the essence of the system S only by studying its interaction with the environment. The view of the system as a unified whole is developed by introducing the concept of “connection”. Further, the whole complex of system connections and their characteristics leads to the concepts of system structure St and complexity. In structural studies, a set-theoretic description of the system in terms of the theory of relations, including the language of cognitive maps, is particularly effective. Graphs are a universal means of describing the structures of systems. Depending on the elements, structural diagrams and signal graphs are used.

The structural scheme is an oriented graph consisting of a set of vertices $W = \{w_i\}$ and a set of arcs $E = \{x_i\}$.

The arcs of the structured graph correspond to the variables X_i, $i = 1\ldots, k$, and at the vertices, the variables are summarized and the sums are transformed according to the transfer functions:

$$X_i(s) = w_i(s)\, \Sigma j\, x_j\,(s)$$

In the language of binary relations, a stultified graph is defined as a pair of vertex sets $w_i \in W$ and arc sets $x_i \in X$

$$G_c = \langle W, X \rangle$$

The arc (w_i, w_j) of a graph specifies causal relations; this arc corresponds to the variable x_i.

Signal graphs are a convenient form of representation of control system models.

A model in the form of a signal graph is defined as a binary relation *W* on the set of variables *X*.

Mathematically, a cognitive map is a sign-oriented graph:

$$G = \langle V, E \rangle \quad (1)$$

где V — many factors of the situation (vertices, objects, and concepts), vertices $V_i \in V$,

$i = 1, 2, \ldots, k$ are elements of the system under study;

E – the set of causal relationships between the factors of the situation (arcs),

arcs $E_{ij} \in E$, $i,j = 1, 2, \ldots, N$ reflect the relationship between the vertices V_i and V_j;

The tools of cognitive modeling can vary depending on the goals and objectives of the DSS. Some of them include:

Cognitive maps (Mind maps) are graphical models that display connections between ideas and concepts that can be used to study decision-making. Maps can be used to visualize conceptual relationships and facilitate the decision-making process.

Causal relationship diagrams are a methodology that is used to determine causal relationships between events. Cause-and-effect diagrams help identify factors that influence decision-making and allow you to develop strategies more effectively.

Event and process modeling is a method that is used to create models that display the processes that occur in the system. These models can be used to analyze system performance and to determine the best decision-making strategies.

Cognitive agents are tools that are used to model human thought processes. These tools make it possible to analyze decision-making and predict the results of decisions made.

1. Expert systems are computer programs that use the knowledge of experts to make decisions. Expert systems can be used to analyze the decisions made and to determine the best strategies.

2. Scenario modeling is a technique that is used to create models that depict different scenarios of situations.

For the organization of research work and the development of a consistent action program, the "meta-laboratory of the description of the object (system)" (Gorelova & Pankratova, 2015) is used, which is also a "meta-model of research" (2). This model includes an "observer"—a meta-laboratory that takes into account the influence of the researcher on the system and its research.

$$M = \{M_O(Y, U, P), M_E(X), M_O, M_D(Q), M_{MO}, M_{ME}, M_U, M_H, A\} \quad (2)$$

где $M_O(Y, U, P)$ – identifying the model of the system (object model) in which Y are endogenous variables,

U – vector of controlled variables,

P – resource vector; $M_{E(X)}$ – environment model,

X – exogenous values;

$M_{OE} = \{M_{SX}, M_{SY}\}$ – model of object–environment interaction;

$M_D(Q)$ – system behavior model,

Q – B disturbing effect;

M_{MO} B M_{ME} – models for measuring the state of the system and the environment; MU – model of the control system,

A – rules for combining models and selecting processes for changing an object;

MH is a model of an "observer" (a cognitive engineer, expert, or researcher).

The MO, ME, and MORE models are cognitive models. The MD system behavior model is a model of an impulse process that describes the evolution of the situation on the model when disturbing influences are introduced. The MH observer model is part of the cognitive modeling process that reflects the process of cognition by the subject of the studied object. Let's consider the signal graph in the example of the graph by Magoro Maruyama. One of the historical examples of a cognitive map of a complex system is the model developed by Magoro Maruyama and designated by him as a "Landmark Digraph for Analyzing Solid Waste Disposal Problems" (Gorelova & Kalinichenko, 2018). To create this model, a cognitive modeling software system was used (a program for cognitive modeling and analysis of socioeconomic systems at the regional level).

When:

V_1 – Number of inhabitants in the city

V_2 – Improving living conditions in the city

V_3 – Amount of garbage per unit area

V_4 – Number of diseases

V_5 – Number of inhabitants in the city

V_6 – Bacteriological contamination per unit area

V_7 – Number of treatment facilities

The Cognitive map G1, "The Sign Orgraph for Analyzing Solid Waste Management Problems," was developed by Magoro Maruyama using Formula 1.

For further modeling of the development of the situation, pulse modeling can be used (Gorelova et al., 2006).

$$x_i(n+1) = x_{vi}(n) + \sum_{j=1}^{k-1} f_{ij} P_j(n) + Q_i(n) \quad (3)$$

where

$x_{i(n)}$ – the magnitude of the pulse at vertex V_i at the previous moment—the simulation cycle – n,

$x_{i(n+1)}$ – at the moment of interest to the researcher $(n + 1)$;

f_{ij} – pulse conversion coefficient;

$P_{i(n)}$ – the value of the pulse at the vertices adjacent to vertex V_i;

$Q_{i(n)}$ – the vector of disturbances and control actions introduced into vertices V_i at moment n. This is the initial impulse.

In pulse modeling, the situation is determined by a set of values Q and X, which changes in each simulation cycle. A set of implementations of impulse processes is a "development scenario" that indicates possible trends in the development of situations. Formula 3 was used to show with arrows the effect of one vertex on another vertex in Figure 1, impulse impact = +1, —1 since it is impossible to quantify the impact of one node on another. To build this model, statistical data from sources was analyzed (Official website of the Territorial body of the Federal State Statistics Service for the Rostov region//Rostov region in numbers (2021): Brief statistical collection/Rostovstat. – Rostov-n/D, 2022. [Electronic resource]. – URL: https://61.rosstat.gov.ru/folder/30195.; Official website of the Federal State Statistics Service. [Electronic resource]. – URL: https://rosstat.gov.ru/folder/11109.; Official website of the Industrial Development Fund. [Electronic resource]. – URL: https://frprf.ru/(access date 03/10/2023). These data allow us to determine the quantitative values of the vertices V_1, V_2, V_3, V_4, V_5, V_6, and V_7.

III. Research Results

The analysis of statistical data has shown that such indicators V_2, V_3, and V_5 are absent in the analyzed collections. Therefore, the use of cognitive modeling

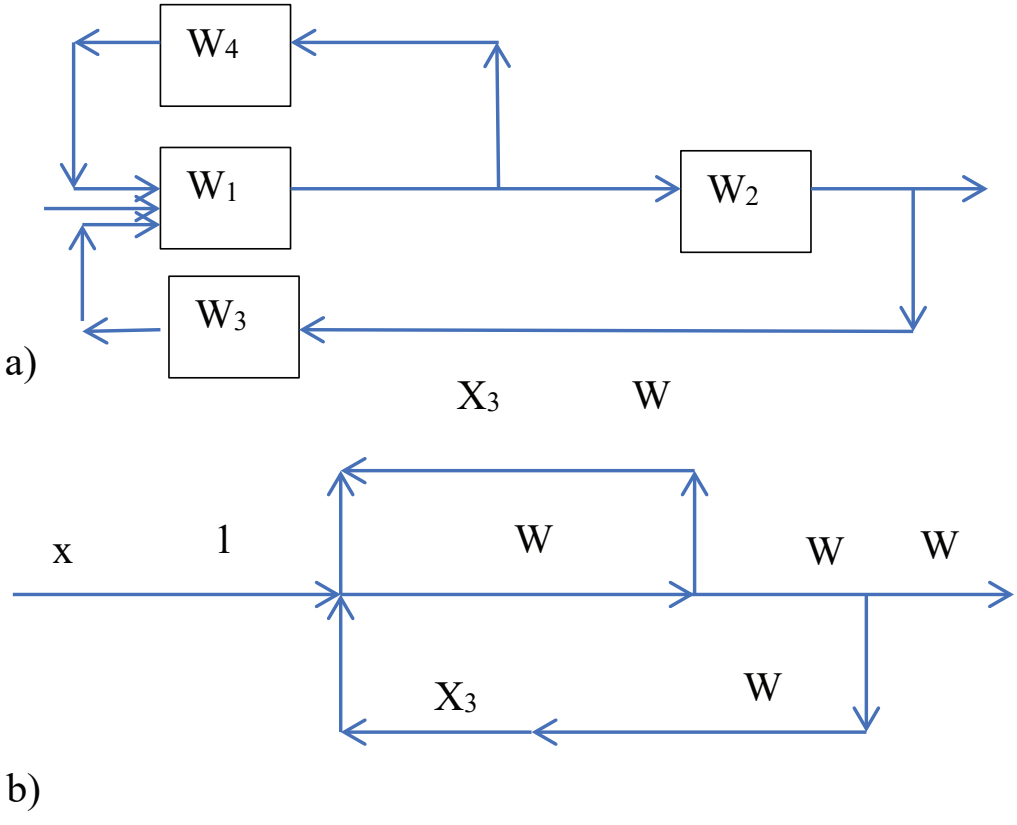


Figure 1: (a) Structural graph. (b) Signal graph.

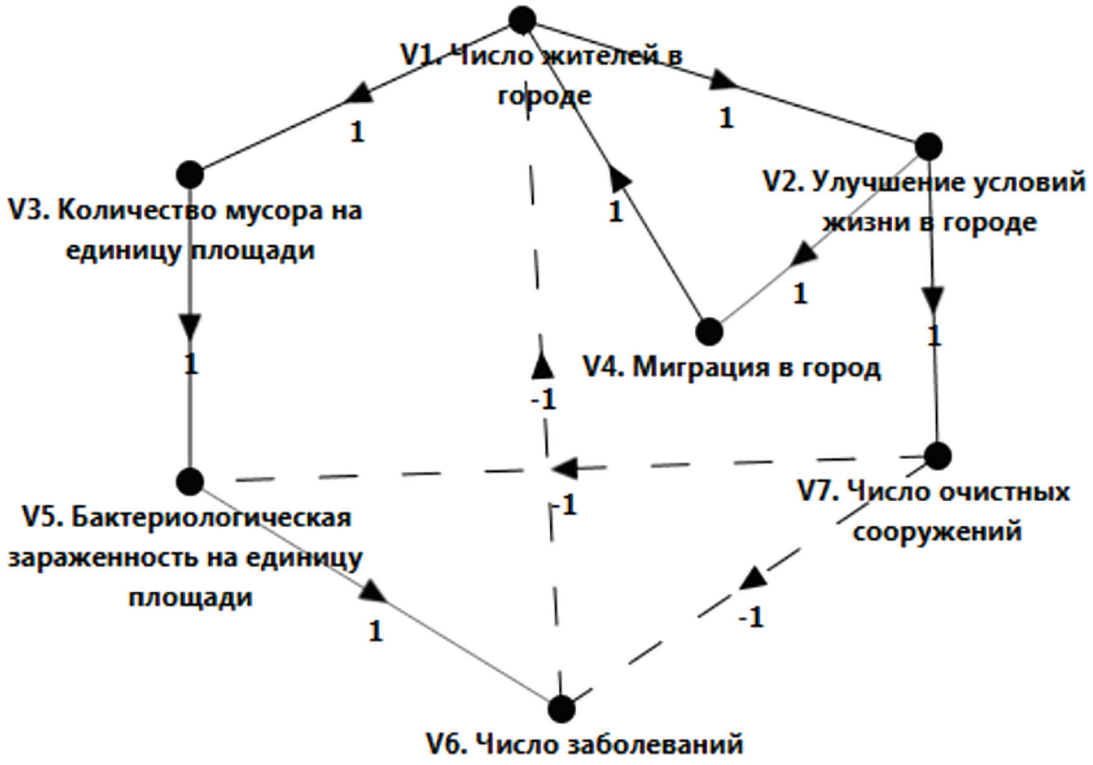


Figure 2: Cognitive map G1, "The Sign Orgraph for Analyzing Solid Waste Management Problems," by Magoro Maruyama.

allows for building a forecast without precise quantitative data (Official website of the Territorial body of the Federal State Statistics Service for the Rostov region//Rostov region in numbers (2021): Brief statistical collection/Rostovstat. – Rostov-n/D, 2022. [Electronic resource]. – URL: https://61.rosstat.gov.ru/folder/30195.; Official website of the Federal State Statistics Service. [Electronic resource]. – URL: https://rosstat.gov.ru/folder/11109.; Official website of the Industrial Development Fund. [Electronic resource]. – URL: https://frprf.ru/(access date 03/10/2023). At the moment, there are several software tools for cognitive modeling of complex economic systems. They are based on various modeling methods, such as agent modeling, system dynamics modeling, and network modeling, to describe economic systems.

The analysis of programs for cognitive modeling of complex economic systems allowed us to identify the following (Makarenya et al., 2023):

1. NetLogo is an agent-based modeling software that is widely used in economics. It allows users to create and model complex economic systems such as market dynamics, social networks, and game theory models. NetLogo has open-source code and a large community of users who contribute to its development.
2. Vensim is a system dynamics modeling software that is used to model complex economic systems. This allows users to create dynamic models of economic systems, such as macroeconomic models, environmental models, and business models. Vensim has a number of functions for data analysis and visualization (Karimov, 2017).
3. GAMA is an agent-based modeling software that is used to model complex economic systems. It provides a number of modeling methods, such as multi-agent systems, spatial models, and social simulations. GAMA has an open-source code and a user-friendly interface (GAMA platform) (GAMA platform).
4. Repast is an agent-based modeling software that is used to model complex economic systems. It provides a number of modeling methods, such as multi-agent systems, social networks, and spatial models. Repast has an open-source code and a large community of users (Yakimov et al., 2016).
5. Arena is a modeling tool that is widely used in manufacturing, logistics, and services. It offers a



Figure 3: xxxx

drag-and-drop interface for creating simulations and supports a wide range of simulation methods. Arena also provides statistical analysis tools for evaluating simulation results (Vysochina et al., 2012).

Russia also has a number of software tools for the cognitive modeling of complex economic systems. Among such tools, software complexes can be distinguished, which, unlike editors like Mind maps, have advanced functionality for analyzing the constructed model and pulse modeling.

Among them, one can single out the Canvas DSS (Kulinich, 2002), which allows for conceptual analysis and modeling of complex and insufficiently defined political, economic, or social situations. This system can be used to develop management strategies and mechanisms for their implementation, as well as to create policy documents for the strategic development of a country, region, enterprise, firm, etc. In addition, it can be used for continuous monitoring of the state of the situation, generating and testing hypotheses about the mechanisms of development and management of the situation (Makarenya et al., 2023).

This also includes the program being developed for cognitive modeling of complex CMCS systems (Gorelova & Kalinichenko, 2018) as well as full-fledged complexes to support strategic decision-making in the fields of economics, politics, sociology, military–political conflicts, medicine, etc., such as CoSMoS (Silov, 1995), IGLA (Korostelev et al., 2008), Compass (Kulinich & Maksimov, 1998), and others.

These tools allow you to quickly and comprehensively characterize complex and uncertain situations, as well as offer qualitative solutions to problems in these situations, taking into account environmental factors and a systematic approach.

But, none of the above software products has an information and analytical system for accounting for industrial production, which could be used to conduct PEST analysis and build input cognitive maps.

It can be seen that it is quite difficult to understand the factors, the impact on the factors, and the main directions of industrial development.

The authors propose the development of such an information and analytical product that would collect data from industrial enterprises, and form databases of industrial products in natural units of measurement that can be used for cognitive modeling and machine learning in order to build predictive development scenarios. The interface of this software product may look like this (Figure 3).

Each of the modeling systems has its own strengths and weaknesses, and the choice of modeling tool depends on the subject area, modeling requirements, and user preferences.

Currently, the cognitive approach is widely used in intelligent management DSS. It allows you to combine formalized scientific knowledge with the experience of experts and the creative potential of decision-makers. The results of cognitive modeling of complex systems belong to the field of artificial intelligence, and are also used to create intelligent DSS (ISPR).

IV. Discussions

The disadvantages of quantitative forecasting methods are that there must be a database of data for at least 5 years on the basis of which forecasts are based (for example, the exponential smoothing method). Such databases are not always available. This makes it difficult to use quantitative forecasting methods. For cognitive modeling, it is necessary to carry out pest analysis, which does not require a data set for 5 years. Therefore, the cognitive modeling method is easier to use.

The disadvantage of the cognitive modeling method is that the resulting development forecasts provide a qualitative assessment, and not quantitative indicators of the development of the system under study. For example, it is impossible to predict how many pieces of a product should be produced using the cognitive modeling method. This is a disadvantage of this method. However, the cognitive modeling method makes it possible to determine the direction of development of a weakly structured system under the influence of regulatory factors—the tops of causes, that is, it is possible to predict what needs to be done in the future.

Therefore, it is possible to use cognitive modeling when modeling socioeconomic processes. This method can be used by both scientists and

government authorities. In a situation where the political and economic situation changes dramatically, cognitive modeling makes it possible to build forecasts for the development of socioeconomic, regional, and sectoral systems

V. Conclusion

In general, the use of a cognitive approach in the management of socioeconomic systems has shown promising results in improving productivity and results. By better understanding the cognitive processes underlying behavior in the system, managers can identify areas for improvement and develop more effective strategies to achieve their goals. However, further research is needed to fully understand the potential benefits and limitations of this approach, as well as identify best practices for its implementation. The study showed that cognitive modeling is a tool for predicting loosely structured systems when there is no quantitative data from statistical reports.

Further directions of research are to compare the obtained cognitive models with quantitative predictions.

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Acknowledgments

The study was supported by grant No. 23-28-00537 of the Russian Science Foundation, https://rscf.ru/project/23-28-00537/

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