Cognitive modeling of the development of complex managed systems

Baidakov A N, Nazarenko A V, Babkina O N

Stavropol State Agrarian University, Zootekhnichesky Lane, 12, Stavropol, 355017, Russia

E-mail Nazarenkoa.v@yandex.ru

Abstract. The purpose of this research is to form a set of methodological provisions related to the use of cognitive modeling in the management of complex systems in conditions of high dynamism of studied processes. The rapid development of information and analytical tools provides new opportunities for applying cognitive modeling to a wider range of systems. The methodological basis of the study is the system methodology and its direct implementation is based on the system sequence "mission – goal – functions - structure – behavior – result". Cognitive modeling in the management of complex systems takes into account their hierarchical structure, which entails the hierarchy of the corresponding models, which is directly reflected in the generated models or considered when building local models for systems of a certain hierarchy level. Complex systems also determine the complexity of the models that represent them. Therefore, the paper proposes stratification of the modeling process and its results on five levels: the representation model, the understanding model, the interaction model, the management model and the behavior model. The dynamics of simulated systems and their external environment assumes an iterative (cyclic) nature of cognitive modeling. The paper presents a structural cognitive model of managing the functioning and development of complex systems as its result.

Keywords: modeling in management, system modeling, cognitive modeling, cognitive model of management of complex systems.

1. Introduction.
Our ideas about any objects and processes are always some of their models formed using a particular modeling language. Therefore, research on theoretical and methodological problems of modeling is always relevant. At present, the importance of solving such problems and their scale, as well as the volume of relevant information sets and knowledge, have increased enormously. But on the other hand, new modeling tools are appearing. All this together determines the necessity and productivity of using a cognitive approach to modeling in relation to the management of complex systems [1].

A large number of papers have been devoted to modeling [2, 3, 4], however, there is a lack in research of cognitive implementation in the context of the relevance of solving management problems, especially in the knowledge economy. These circumstances determine the significance and scientific novelty of the presented results.

The purpose of the research is to form a set of methodological provisions of cognitive modeling aimed at creating conditions for its wide application in the practice of managing complex systems.

2. Materials and methods.
The methodological apparatus of the research is based on a system methodology and a cognitive
approach to the problems of management and modeling. The structural cognitive model of managing the functioning and development of complex systems presented in this paper allows us to develop algorithms for managing such systems using a variety of modeling tools.

3. Stratification of modeling.
People in their activities operate with models, carry out their activities based on their models of the universe, society, state, enterprise, family, etc. Its success depends on the adequacy of such modeling.

Let us clarify that by model we mean the subject's representation of an image of some object or process through the use of some verbal, visual, mathematical language.

We can distinguish the following levels (strata) of the purpose of modeling and accordingly its course, goals and results in terms of their perception and use by the subject of management [5]:
- representation model as a formalized or often nonformalized appearance of a certain phenomenon in the subject of management, preliminary from the point of view of purposeful modeling;
- understanding model as semantic and causal (if possible) picture of the state and dynamics of changes in the studied phenomenon, common to the customer and performer of modeling;
- interaction model as a structural model represented by the main elements (subsystems) of the system under study and its connections, including connections with the external environment;
- control model as the actual model of the phenomenon under study as a control tool with inputs (control actions) and outputs (expected results of the functioning and development of the controlled system);
- behavior model as representations of the modeling customer about the place, role, order of use and effectiveness of the management model in the processes of functioning and development of the managed system-operational and evaluation.

Depending on the tasks to be solved, such differentiation can be considered both as a set of submodels of the same object of research and as independent results of the formation stages and use of models in management. Additionally, each subsequent submodel necessarily includes the previous one, but already expanded with new knowledge.

These levels, in fact, represent the phases of the cycle of formation and development of the model in management from the unconscious use of the representation model to understanding the need for purposeful modeling, setting its goals and objectives, and then to understanding the need to build a new model, based on the previous or fundamentally different one.

Thus, modeling in management is a continuous cyclic (iterative) process. The transition to the next level of modeling is carried out as a result of purposeful increment of knowledge about the phenomenon under study, that is, it is inherently cognitive. This means that this is also the process of modeling.

The first three model levels (modeling phases) form a model image of the perception of controlled objects and processes, the last two form a tool and mechanism for management actions using modeling.

Let us pay attention to inevitable and unremovable subjective component of any model-based approach to managing complex systems [6, 7].

The world is constantly changing and its perception by customers and modeling performers does the same. This means that the ideas about objects and modeling processes and their understanding are also changing. Therefore, either the model of interaction between subjects and objects of management or models used in management must constantly change.

4. The consistency of the simulation
Continuous changes in the characteristics of the managed system and its environment, their high dynamism, the need to reduce the negative consequences of subjectivity in management determine the conditionality. Moreover, the vital need to develop new knowledge about these processes in order to ensure timely adaptation to them. This means that the coordinated formation and competent use of the complex of the above five model levels (modeling phases) for complex systems is possible only on the basis of a cognitive approach to the processes of their functioning and development.

The specified modeling cycle should reflect the characteristic features of the managed system and its
management mechanism, take into account the influence of significant supersystems, rationally use the available diverse resource opportunities for the functioning and development of the system, the structure and content of the implemented rules and management procedures, including their instrumental implementation.

In general, the models used in managing a complex system can be represented as a tuple

\[ M_i = \langle R_i, R_e, Y_i, X_i, I_i, D_i, F_i, R_\alpha \rangle, \]

where \( i \) is hierarchical level of the modeled object or process;
\( R_i \) is model reduction level;
\( R_e \) is modeling resource support;
\( Y_i = (y_{i1}, \ldots, y_{in}) \) is output variables;
\( X_i = (x_{i1}, \ldots, x_{im}) \) is factor variables;
\( I_i \) is modeling tools;
\( D_i \) is information support;
\( F_i = (F_{i1}, F_{i2}, F_{i3}, F_{i4}, F_{i5}) \) is the form of providing results that corresponds to each of the five phases of modeling;
\( R_\alpha \) is rules for implementing procedures for using, updating, and developing the model.

System regularities of isomorphism and isofunctionalism allow us to use the above provisions in the formation of models and mechanisms for managing the functioning and development of systems at any level.

The structure of complex systems and their management mechanisms and, therefore, the corresponding models used in management, has a hierarchical structure, which is reflected in the corresponding hierarchy of the management system. This position also means that a hierarchy of management models is required. We are also talking about cyclic stratification of models with five modeling phases, presented above.

As a basis for forming a vertical hierarchy for studied systems, we can consider, for example, the construction "country-region-enterprise". It would seem that it would be possible to build a corresponding model with a tree structure. However, in practice, modeling is usually performed separately at each level. And the problem is not the reluctance to build such a large model that covers all levels and subsystems. Several "simple" questions arise at once: What is the purpose of such a model? Who are the customer and the contractor? How much time and resources are needed to build, operate, and update it? Is it possible to force businesses to participate in this simulation? The list of such questions can be continued.

It is clear, that such bulky structures often do not justify themselves. At least for the time being. And for each level of the hierarchy, such models are needed. And even if they are built seemingly independently of each other, the system approach to modeling requires that they take into account the relationships of the system under study with adjacent (and not only) levels of the hierarchy. This means that there is at least a latent hierarchy in the simulation, even if it is localized. In other words, each systematically constructed model in management necessarily assumes its "embeddedness" in the existing or possible hierarchy of the corresponding management models.

Violation of this condition should be perceived as a disregard for the system approach, and therefore, potentially dangerous use of modeling methods in the practice of managing fairly complex systems.

Modeling in the management of complex hierarchical systems should be considered from the perspective of a dynamic correlation of their various components and properties: general, specific, certain; functional; structural; behavioral and effective. The integrating position in the definition and systematic use of these positions and categories in modeling is their inclusion in the system sequence "goal – functions – structure – behavior – result", based on the well – known approach of D. Bain "structure – behavior – result" [1].

The fractality property, which we consider in two aspects as the fractality of systems and the fractality of processes, deserves special attention within the framework of the system and, as a result, the cognitive approach to management.

The fractal approach, as we know, proceeds from the self-similarity of the studied objects and
processes: in our case not geometric self-similarity, but structural and semantic. Among the main fractal features of complex controlled systems, we include:
- system properties and patterns;
- purposeful functioning and development;
- hierarchical certainty;
- availability of management;
- openness.

The number of process fractal features of controlled systems should also include their inherent multi-level cyclical functioning and development, which determines the cyclical nature of cognitive modeling.

5. The cognitive control model

The practical implementation of the system approach should be based on the methodology of cognitive modeling, since it is not enough to use the accumulated knowledge and methods. It is necessary to constantly generate and effectively use in practice new knowledge and methods that meet emerging problems and challenges.

The concept of "cognition" in relation to modeling is understood in a broad sense. This means using in management not only the existing knowledge about the objects and processes under study, but also necessarily creating prerequisites, defining subjects and ensuring the processes of their formation [8].

In the context of globalization and high dynamism of social and economic processes, the identification and determination of ways to solve emerging problems based on a cognitive approach in the course of functioning and development of a managed system should be based on modern methods of generating, practically oriented representation and targeted interpretation and projecting existing and new knowledge to solve problems. And the rapidly increasing power of modern information and analytical tools allows us to increasingly translate the cognitive approach into a broad practical plane.

The proposed structural cognitive model for managing the development of complex systems (Figure 1) is based on a systematic approach to research. It defines the place and role of cognitive research in the structure of the "mission-goal-function-structure-behavior-result" system sequence.

The factors of influence on the studied system in the cognitive model are grouped in the main directions:
- natural global and local environment;
- social environment by level: personal, group, enterprise, municipal, regional, state, international;
- the institutional environment that determines the conditions for the functioning and development of the studied systems: social, economic, political and legal.
The cognitive model of controlled systems development is structured according to semantic blocks: target, cognitive, functional, structural, effective and regulatory. This approach allows us to combine the analytical and synthetic components of system research, its theoretical and methodological tools, as well as the methodology of its practical implementation in the model.

The target block is a key component of targeted development of the managed system. It combines the mission, goals of the system and the subject of its management – the DM (decision-maker). A complex of internal and external conditions of functioning and development influence the target settings of the functioning and development of the studied systems [9].

The adequacy and success of goal formation processes is directly dependent on the level of awareness of the DM about cause-and-effect relationships both within the managed system and with its external environment. However, modern cognitive capabilities are not always used in goal formation processes, even if they are available to the DM.

A separate factor in the success of management is the level of analytical skills of people who develop and make decisions, their awareness, readiness and practical desire to regularly use modern information and analytical tools.

The formation of a hierarchical structure of the goals of the system and its subsystems should proceed from their existing or being formed organizational and functional hierarchy. This means that it is necessary to ensure organic connections between two hierarchical structures – goals and functions.

The formation and updating of these structures is a non-trivial and contradictory task. The set of contradictions between the functions and structure of the system combines both the contradictions of various functions of the managed system, its subsystems and its inter-level contradictions.

The cognitive block of the model is an active theoretical and methodological component of the formation and use of knowledge. It is directly involved in cognitive activity during the development, decision-making and implementation processes. The decision block is included to the cognitive module of the model.

The possibility of a different composition of the cognitive block is also allowed.
In this study, the cognitive block of the model is represented by the following semantic components:

- theoretical and methodological module combines theoretical and methodological provisions and knowledge used to ensure the functioning and development of the managed system, both existing and new, generated in the course of relevant activities within the system under study and/or outside it;
- the information base, although organically included in the block under consideration, is intended for information support of all processes of functioning and development of the managed system;
- pre-modeling mainly refers to the phases of representation and understanding:
  • in the case of the initial modeling cycle the formation of an information base, identification and structuring of the problems to be solved, their preliminary qualitative and quantitative analysis, the formation and structuring of information aggregates, time series analysis, multidimensional statistical and trend analysis, etc.; setting the modeling problem, establishing its resource capabilities and reduction level; determining the list of effective and factor indicators, the order of use, verification and updating of models, the formation of contours of forecast scenarios;
  • in the case of subsequent cycles (iterations) of modeling-updating the information base, clarifying the problem to be solved and setting the modeling task, increasing the resource capabilities of modeling, updating the list of performance indicators and factors taken into account;
- modeling refers to the understanding, interaction, and management phases:
  • in the case of the initial modeling cycle the construction of a verbal conceptual model, its subsequent formalized representation, the formation of a synthetic mathematical model based on models for each level of the studied systems, determining the instrumental capabilities of the numerical implementation of the model, its verification and validation, the numerical implementation of the model;
  • in the case of subsequent cycles (iterations) of modeling-updating and development, numerical implementation of the management model using new knowledge obtained during the previous stage of modeling and new information; analysis and evaluation of changes in the modeling conditions, including its resource capabilities; assessment of the adequacy of the model to the changed conditions of functioning and development of the system;
- postmodeling refers to the behavior phase for all modeling cycles, means the use of the built model in management practice: conducting calculation operations, forecasting, including scenario, virtual economic experiments, stress testing, determining ways to improve the model and its implementation tools, identifying trends that are practically significant for the development of the system under study, conclusions and conclusions developed during modeling;
- solution block – development of solutions using the results of modeling and forecasting; decision making and implementation with the involvement of the DM in cognitive processes.

The cognitive functional-structural approach to managing a complex system is focused primarily on the purposeful formation of its required emergent effect, or rather, a set of emergent main and additional effects, as a result of "behavior", that is, the goal-oriented scientifically based activity of the controlled system.

The practical implementation of cognitive activity in the framework of the presented cognitive block is carried out through the formation and implementation of appropriate algorithms for system information and analytical activities that meet the structural cognitive model (Figure 1).

6. Discussion
Despite the fact that the obtained results fully meet the goal of the study, in the future, in our opinion, when forming cognitive models used in management, more attention should be paid to its cyclical nature. It is also necessary to consider the issues of personnel support for cognitive modeling, since this part, in our opinion, is currently its most problematic area.

7. Conclusion
The study of the problems of cognitive modeling in the management of complex systems was devoted to the consideration of its two main aspects: organizational and chronological. The first one allowed us to determine the role and place of cognitive modeling in the mechanism of managing complex systems. The second aspect of the research is devoted to the consideration of the internal structure of such modeling processes, represented by five levels, the implementation of which quite definitely sets the chronological sequence of the corresponding phases of modeling. The same aspect is related to the requirement of continuity of modeling processes, with its necessary iterative character as a reaction to constantly changing conditions for the functioning and development of complex systems.
Thus, cognitive modeling of functioning and development of complex managed systems is an effective and practically significant tool for information and analytical support of improving their efficiency at the present stage of socio-economic development of society.

References

[1] Bain J 1951 Relation of Profit Rate to Industry Concentration American Manufacturing, 1936 - 1940 Quarterly Journal of Economics Vol 65 (3) 293 – 324

[2] Hyun J-Y 2019 Using a coupled agent-based modeling approach to analyze the role of risk perception in water management decisions Hydrology and Earth System Sciences 23 2261-2278

[3] Kucherova H 1951 Modelling tax consciousness evaluation in the context of economic development uncertainty Periodicals of Engineering and Natural Sciences 7 567-579

[4] Baydakov A, Chernikova L, Nazarenko A, Zaporozhets D, Sidorova D 2017 Scenario forecasting of the reproduction process in the agriculture in view of inflation Journal of Environmental Management and Tourism 8 (3) 620-628

[5] Lutsenko E, Troshin L, Zviagin A, Zviagin A, Milovanov A 2018 Application of the automated system-cognitive analysis for solving problems of genetics Journal of Mechanical Engineering Research and Developments 41(2) 1-8

[6] Raymond D 2006 Cognitive Analysis of Problems of Comprehension in a Learning of Mathematics Educational Studies in Mathematics 61(1) 103-131

[7] Gorelova G Pankratova N 2018 Strategy of Complex Systems Development Based on the Synthesis of Foresight and Cognitive Modelling Methodologies IEEE First International Conference on System Analysis & Intelligent Computing (SAIC)

[8] Schwartz M Cook C Pressey R Pullin A Runge, etc 2017 Decision Support Frameworks and Tools for Conservation Conservation Letters 11(2) 1-12

[9] Raymond D 2006 A Cognitive Analysis of Problems of Comprehension in a Learning of Mathematics Educational Studies in Mathematics 61(1) 103-131