Strategy for the Study of Interregional Economic and Social Exchange Based on Foresight and Cognitive Modeling Methodologies

N. D. Pankratova[1 [0000-0002-6372-5813]], G.V.Gorelova[2 [0000-0001-6637-6586]], V.A.Pankratov [3 [0000-0002-8264-5835]]

[1] Institute for Applied System Analysis, Igor Sikorsky Kyiv Polytechnic Institute, Ukraine
natalidmp@gmail.com

[2] Engineering and Technology Academy of the Southern Federal University, "ITA SFEDU" Russia, Taganrog
gorelova-37@mail.ru

[3] Institute for Applied System Analysis, Igor Sikorsky Kyiv Polytechnic Institute, Ukraine
pankratov.volodya@gmail.com

Abstract. The proposed strategy for the study of interregional economic and social exchange is based on the simultaneous application of foresight and cognitive modeling methodologies. The foresight methodology is applied at the first stage of complex system modeling and the obtained results are used as input data for the cognitive modeling stage. A toolkit for the construction a cognitive map with a convenient and simple user interface is developed. The computational algorithm and software modules provide verification of the structural stability, stability at the initial value and perturbation. In the process of cognitive modeling, the creation of possible scenarios for the development of the system under the influence of various control and perturbation influences is carried out. It gives the possibility to determine the conditions for advancement for the system of interregional economic relations aimed at improving the quality of life of the population in the considered regions.

Keywords: Foresight, Cognitive modeling, Interregional exchange, Toolkit, Stability, Impulse modeling, Scenarios.

1 Introduction

The experience of the leading countries of the world shows that the success in the social and economic activities of the state under current conditions of globalization of the world economy is largely ensured by the high rates of innovative development of scientific, technical, manufacturing and technological potentials and high levels of competitiveness of national high-tech products on the world market. The study of the social and economic activity of the state requires a systematic approach, an understanding of the complexity of the systems, the regulation of which needs scientific planning and forecasting [1].

In many countries, primarily to develop a long-term vision of the innovative development of the industry, science and technology as the main components of the state's economy, the methodology of foresight is used. On its basis, a systematic process of "identification" of key future technologies (critical technologies, alternative scenarios) is carried out to help representatives of the highest governing bodies of the economic sphere of the state, industries or individual institutions and companies to form the most effective science and technology policy and plan its development. The governments of all countries are gradually forced to "engage" in the process of foresight, because the successful use of the achievements of science and technology increasingly depends on the creation of effective links between business, innovation, scientific and educational institutions and the branches of the government responsible for the development of a society.

A cognitive modeling methodology is used to build scenarios for the desired future. Cognitive modeling technologies that belong to the class of simulation modeling are designed to understand, explain, and describe a complex system, and determine possible ways to manage situations in a complex system in order to transition from the initial state to the desired one, based on cognitive modeling. At the same time, in cognitive modeling, as in any simulation modeling, a subjectivity takes place when providing initial data on the subject area considered in the process of determining the vertices of the graph, the subjectivity in determining the arcs of the graph, reflecting the causal relationships between the vertices, in the inclusion of weights and functions arcs of the graph. In order to mitigate subjectivity, it is proposed to use the foresight methodology at the first stage and to use the obtained results as the initial data at the cognitive modeling stage.

The purpose of this paper is to develop, using the methods of foresight and cognitive modeling, the system of interconnection of interregional relations elements (entities, concepts) in the form of a cognitive map imitating the mechanism of interregional economic and social integration. In the process of cognitive modeling, the goal is to construct the possible scenarios for the development of the system under the influence of various control and perturbation influences and determine the conditions for improving the system of interregional economic relations aimed at improving the quality of life of the population in the considered regions.

2 Review of the Literature

In semi-structured problems, which include the tasks of an interregional socio-economic integration, it is impossible to apply the traditional mathematical approach to the analysis of the development of complex solutions. For the complex non-formalized systems simulation a cognitive approach based on cognitive aspects is used. These aspects include the processes of perception, thinking, cognition, explanation and understanding. A schematic, generalized description of the picture of the world is depicted as a cognitive map. Technologies of cognitive modeling of complex systems have actively being developed since the middle of the 20th century, including in [2,3] and then, in the same vein, in [4]. Certain theoretical foundations of these works are in [5-9].

Involving foresight methods in the first stage of simulation allows using expert assessment procedures to identify critical technologies and construct alternatives of scenarios with quantitative values of characteristics. With this goal, in the process of implementing the procedure for forming alternatives of scenarios in solving problems of foresight, there is a need to involve expert assessment methods, among which are the most frequently used methods of hierarchy analysis, Delphi, cross-analysis and morphological analysis, methods of SWOT, TOPSIS, VIKOR [1,10]. To substantiate the implementation of a particular scenario and develop other possible development scenarios, cognitive modeling of complex systems is involved, which allows to build causal relationships based on theoretical knowledge and practical experience, to understand and analyze the behavior of a complex system for a strategic perspective with a large number of interconnections and interdependencies and to offer a scientifically based strategy for the priority scenario implementation [4].

The use of foresight and cognitive modeling is an innovative tool for studying the structure, behavior of complex systems, and achieving the desired development strategies.

3 Setting the Task of Modeling Interregional Economic and Social Integration

To implement the actions presented in the diagram in Fig. 1, it is necessary to give some explanations of the complex systems cognitive modeling. Cognitive modeling of complex systems [4] means the phased solution of interrelated problems: taking into account the uncertainty of various nature and multi-factor risks, building a cognitive model (map), studying the model's paths and cycles, determining its resistance to perturbations and structural stability, topological analysis of the model, scenario modeling based on the implementation of impulse processes for alternative scenarios and various control and perturbation influences, choice of scenarios and decision making.

The mathematical form of a cognitive map is usually expressed by the sign oriented graph [4] with a set of vertices $V = \{v_i\}, i = 1, 2, ..., k$ and set $E = \{e_{ij}\}$ of positive $(+e_{ij})$ and negative $(-e_{ij})$ relationships between them $i, j = 1, 2, ..., k$:

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

For creation of a specific cognitive map of interregional economic and social integration, it is necessary to take into account the following facts:

- general economic, social and natural indicators of the studied regions are interdependent, affect the efficiency of interregional economic relations, but not all of them can be quantified, there are indicators (qualitative) that can be set only verbally or in the form of fuzzy data;

- commodity circulation is a determining factor of the success for interregional economic relations, the sectoral structure of interregional commodity exchange significantly influences interregional economic integration;
- the level of transport communication between the regions and its infrastructure, as well as the level of development of communication and the dynamics of import-export products significantly affect the efficiency of inter-regional economic integration;
- the development of interregional economic relations takes place in conditions of both internal and external competition, in the conditions of the current social and political situation in the regions.

In a cognitive study of the problems of the system of inter-regional economic and social integration, one can apply the technique of developing a sequence of cognitive maps to reflect various aspects of inter-regional relations that clarify each other. In this paper, a generalized cognitive map will be presented in which the region is not specified, and the model reflects only concepts (tops) – factors affecting the effectiveness of interregional socio-economic integration for any region. At the same time, the initial values for cognitive modeling are the results obtained using foresight methods [1,10].

4 Creating a Cognitive Model of Interregional Economic and Social Integration

We first construct one of the cognitive G maps, in which we reflect the dependence of interregional exchange on the identified factors of interregional economic and social integration. In the process of developing a cognitive map to support the process of structuring an expert's knowledge in a specific subject area, the capabilities of the CMSS toolkit [11] with a convenient and simple user interface are used. The computational algorithm and software modules provide for the verification of structural stability, stability by the initial value and by perturbation. To determine structural stability, the criterion for the absence of pair cycles is used. To determine the stability by the initial value and with the disturbance, the Lyapunov criterion is used. The system is stable by the initial values if $\max|\lambda_i|<1$ and by the perturbation if $\max|\lambda_i|\leq 1$ where $|\lambda_i|$ are the eigenvalues of the connectivity matrix.

When analyzing a cognitive map, the procedure for obtaining the structural stability is performed by selecting pair and unpaired cycles. The pair cycle (positive feedback) has a positive product of the signs of all its arcs, unpaired (negative feedback) has negative. The pair cycle is the simplest model of the structural instability, since any initial change of a parameter at any of its vertices leads to an unlimited increase in the module of the parameters of the cycle's vertices. Any change in the parameter of any vertex of an odd cycle only leads to an oscillation of the parameters of the vertices.

We illustrate the construction of the initial cognitive map on the example of the study of inter-regional economic and social exchange. Vertices and their purpose are shown in Table 1.

Table 1. Vertices of the $G1$ cognitive map "Factors of inter-regional economic integration".

Code	The name of the vertex	Vertex Assignment
V1	Gross Regional Product	basic
V2	Interregional Economic Integration	target
V3	Socio-economic indicators	basic
V4	Commodity turnover	indicative
V5	Transport Level	managed
V6	Level of communication	managed
V7	Risks	perturbing
V8	Level of production base	basic
V9	Federal and regional regulatory systems	manager
V10	Geographical position	basic
V11	Rivalry	perturbing

The cognitive map is a parametric weighted sign digraph which is presented in Fig. 1.

$$\Phi = \langle G, X, W \rangle, \tag{2}$$

where $G = \langle V, E \rangle$, X are vertex parameters, W are arc weights, which are determined during the study.

The possibilities of presenting a cognitive map in the CMSS software system is illustrated with fig. 1. These are colored vertices and arcs; the image of the vertex with a larger or smaller circle corresponds to the weight ("significance", "importance", "parameter value") of the vertex; selection of the vertex frame; the image of arcs of different thickness, they can be solid (positive arc weight "+") or dash-dotted (negative arc weight "–"). It is also possible to: name and encode a vertex (for example, $V2$. Interregional economic integration), depict arcs (relations) between vertices, their sign and weight ω_{ij} (for example, the arc e_{54} between $V5$ and $V4$ has a "+" sign that is represented as solid line, and weight $\omega_{54} = 4$; the arc e_{74} has a weight of $\omega_{74} = 3$ and the sign "–", which is depicted by a dash-dotted line), the attention is concentrated on it and it is painted in red color. It is possible to call the action (relation, influence) between the corresponding vertices, for example, $V8$ (level of the production base) "affects" $V4$ (turnover). The choice of the name of the vertices and arcs is carried out by an expert in coordination with the purpose of the study. Note that presented in Fig. 1 numbers, colors, sizes are for illustrative purposes only.

Mappings of vertices and arcs along with their parameters and with the ability to make changes to this grid are shown in fig. 2.

All the described possibilities of the CMSS toolkit help the researcher (expert) to

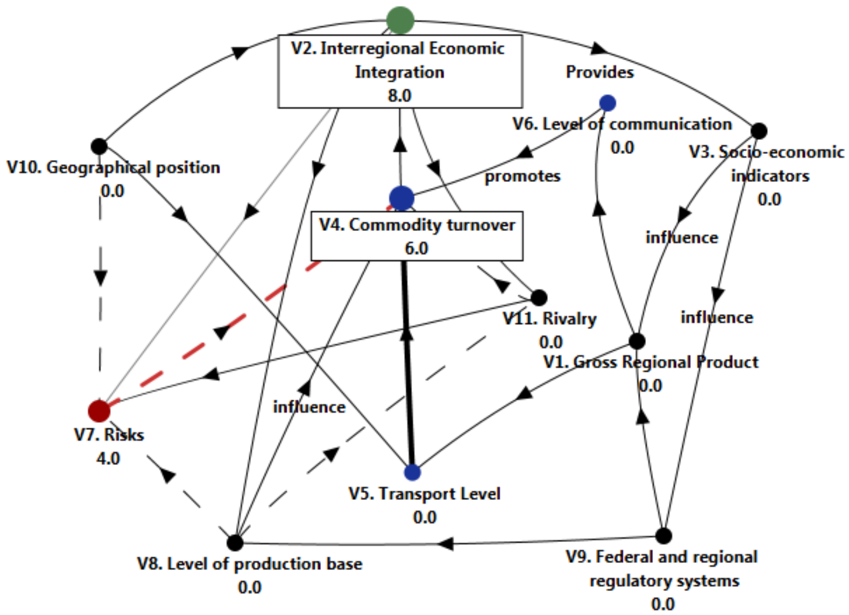
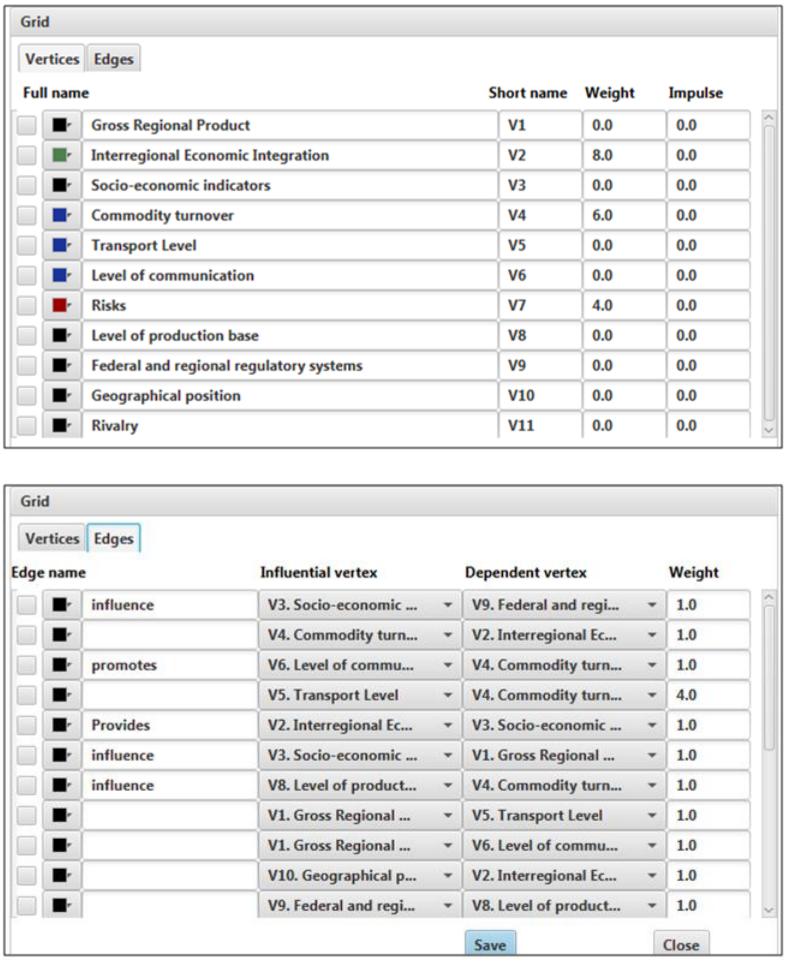


Fig.1. Cognitive map G “Interregional economic and social integration”.

penetrate deeper into the problem of research, varying the number of vertices and arcs, their name, color, size, weight. This ensures the realization of the cognitive abilities of a person, his logical and figurative thinking, reducing the risk of the “human factor” in modeling a complex system. After developing a cognitive model it is necessary to analyze its properties.

Perturbation stability analysis. The results of calculations of the roots of the characteristic equation of the adjacency matrix of the graph G are showed in Fig. 3. Since in this case the maximal root modulus is $|\lambda_i| = 1,6754 > 1$, the system G is stable neither to the disturbance, nor to the initial value. This indicates that the slightest deviations at the vertices lead the system out of the steady state. Making a decision about how “good” / “bad” it is in this case requires the further analysis and refinement of the model.

Analysis of cognitive map cycles. The analysis of cognitive map cycles allows to make a judgment of the structural stability of the system. In Fig.4, for clarity, one of 15 cycles (positive) of model G is highlighted. The model has 12 cycles of positive (amplifying) and 3 negative (stabilizing) feedback. Since there is an odd number of negative cycles, this indicates the structural stability of the system.



Grid — Vertices | Edges

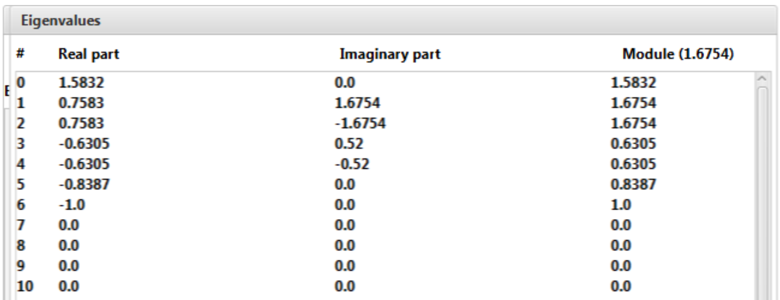
Full name	Short name	Weight	Impulse
Gross Regional Product	V1	0.0	0.0
Interregional Economic Integration	V2	8.0	0.0
Socio-economic indicators	V3	0.0	0.0
Commodity turnover	V4	6.0	0.0
Transport Level	V5	0.0	0.0
Level of communication	V6	0.0	0.0
Risks	V7	4.0	0.0
Level of production base	V8	0.0	0.0
Federal and regional regulatory systems	V9	0.0	0.0
Geographical position	V10	0.0	0.0
Rivalry	V11	0.0	0.0

Grid — Vertices | Edges

Edge name	Influential vertex	Dependent vertex	Weight
influence	V3. Socio-economic ...	V9. Federal and regi...	1.0
	V4. Commodity turn...	V2. Interregional Ec...	1.0
promotes	V6. Level of commu...	V4. Commodity turn...	1.0
	V5. Transport Level	V4. Commodity turn...	4.0
Provides	V2. Interregional Ec...	V3. Socio-economic ...	1.0
influence	V3. Socio-economic ...	V1. Gross Regional ...	1.0
influence	V8. Level of product...	V4. Commodity turn...	1.0
	V1. Gross Regional ...	V5. Transport Level	1.0
	V1. Gross Regional ...	V6. Level of commu...	1.0
	V10. Geographical p...	V2. Interregional Ec...	1.0
	V9. Federal and regi...	V8. Level of product...	1.0

Save Close

Fig.2. Mappings of vertices with their parameters and with the ability to make changes to this grid (fragment).



Eigenvalues

#	Real part	Imaginary part	Module (1.6754)
0	1.5832	0.0	1.5832
1	0.7583	1.6754	1.6754
2	0.7583	-1.6754	1.6754
3	-0.6305	0.52	0.6305
4	-0.6305	-0.52	0.6305
5	-0.8387	0.0	0.8387
6	-1.0	0.0	1.0
7	0.0	0.0	0.0
8	0.0	0.0	0.0
9	0.0	0.0	0.0
10	0.0	0.0	0.0

Fig.3. The results of calculations of the roots of the characteristic equation of the cognitive map G.

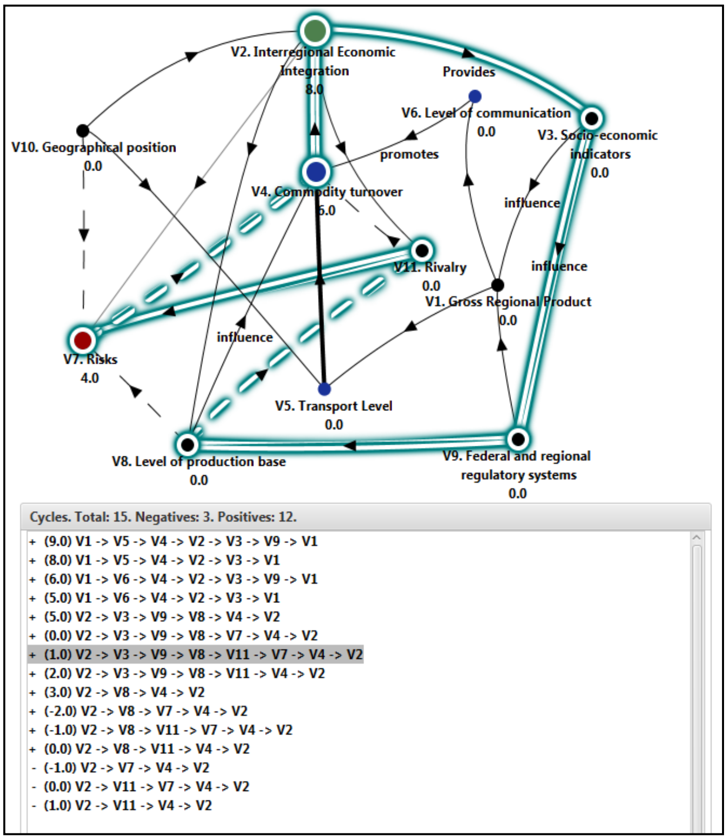


Fig.4. Cycles of the cognitive map G.

5 Creation of Scenarios for the Development of Interregional Economic and Social Integration

The creation of scenarios is based on impulse modeling of the development of situ ions on the cognitive map [11]. Before starting a pulse simulation, it is necessary to think out a computational experiment plan, determining which vertex or set of them should be affected by the impulse q_i. With the help of the CMSS software system it is possible to make positive or negative effects (of any size, normalized) both at all vertices and in their combinations of two, three, etc. Thus, in the experiment, we have a set of effects $Q = \{q_i\}$. Each such impact (combination of effects) generates a scenario of the development of situations. The script scenario the question: “What will happen if ...?”. We present several results of pulse simulations.

Scenario № 1. Let the trade develop intensively $q_4 = +1$; action vector $Q = \{q_1 = 0; \ldots q_4 = +1; \ldots q_{11} = 0\}$ (Fig.5).

The presentation of the results of a pulse simulation according to scenario №1 is divided into two groups of graphs in order not to overload the drawing and to facilitate the perception and analysis of the results. Graphs of impulse processes at 7 and 10 cycles of the simulation are given. The choice of the number of modeling steps for presenting the results depends on the expert (researcher), the software system allows you to simulate any number of steps.

As can be seen from Fig.5, the assumed possibility of the development of commodity turnover between regions leads to trends in the development of situations that can be considered positive for the system in the initial steps of modeling. But the tendency of increasing oscillations in the system due to the impulsive instability of the system ($|\lambda| > 1$) is undesirable.

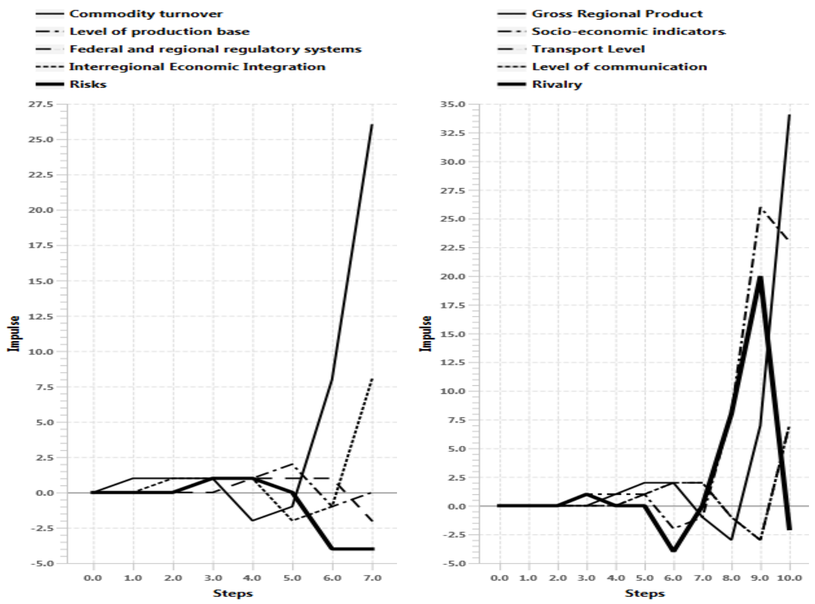


Fig.5. Scenario № 1.

Scenario №2. Let the risks increase in the system, $q_7 = +1$; impact vector $Q = \{q_1 = 0; \ldots q_7 = +1; \ldots q_{11} = 0\}$ (Fig.6).

As can be seen from Fig. 6, the growth of risks leads to a negative development of situations in the system, which does not contradict the “common sense” and may indirectly serve as a judgment about the compliance of the cognitive map with the simulated system of interregional economic and social exchanging.

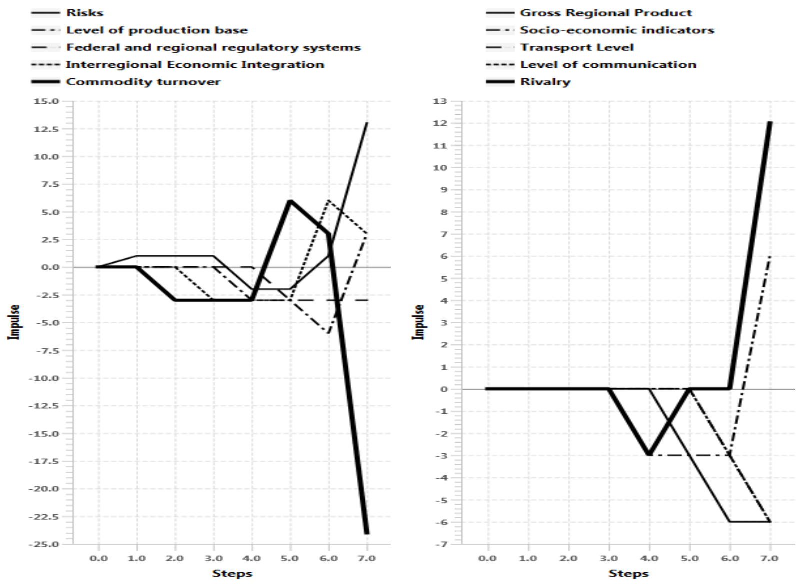


Fig.6. Scenario №2.

Scenario № 3. Let the system deteriorate socio-economic indicators $q_3 = -1$; $Q = \{q_1 = 0; \ldots q_3 = -1; \ldots q_{11} = 0\}$ (Fig.7). As it can be seen from Fig. 7, scenario №3 can be considered pessimistic.

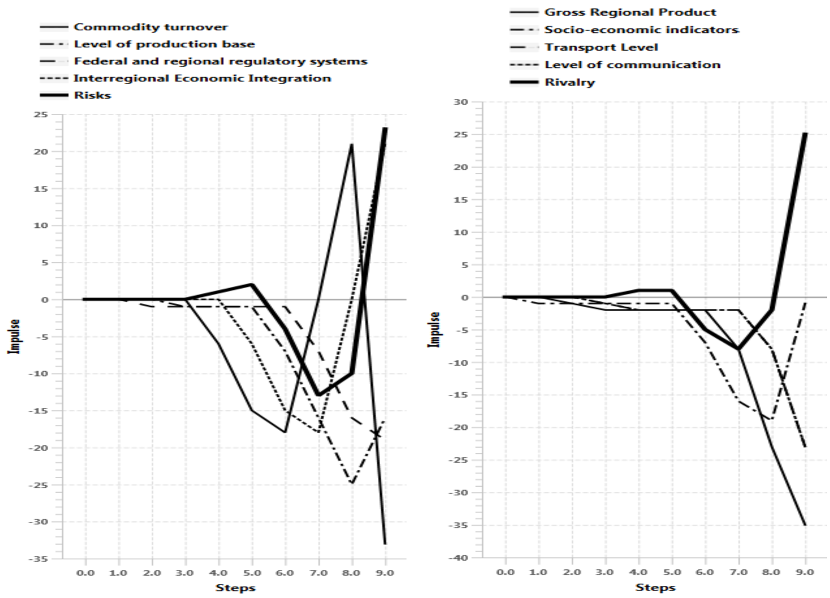


Fig.7. Scenario №3.

Scenario № 4. Let the risks increase in the system $q_7 = +1$, but the federal and regional regulatory systems act “positively”, $q_9 = +1$ and begin to increase the level of the production base $q_8 = +1$q8; impact vector $Q = \{q_1 = 0; \ldots q_7 = +1; q_8 = +1; q_9 = +1; \ldots q_{11} = 0\}$ (Fig.8).

Scenario number 4 can be considered the most optimistic compared with the previous ones. But to select the best scenario for the development of situations it is necessary to carry out further modeling using proposed strategy of an interregional economic and social integration.

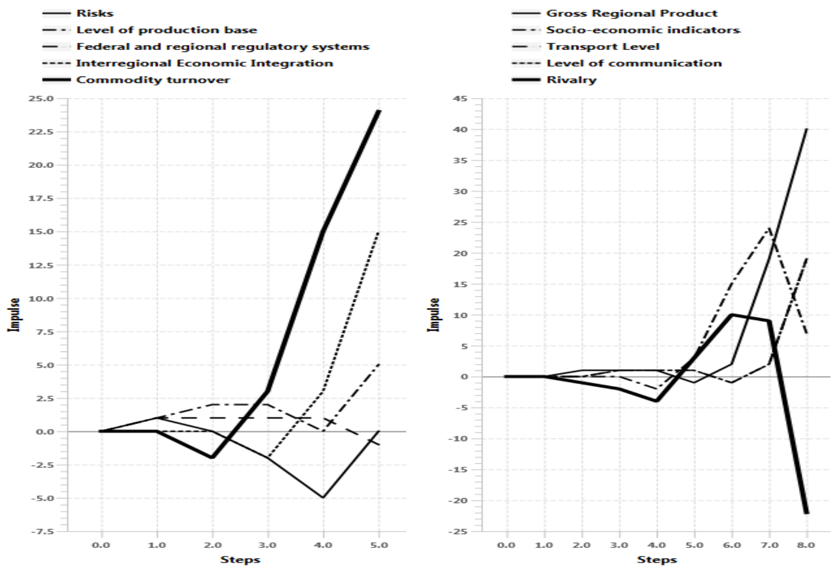


Fig.8. Scenario №4.

6 Conclusion

The results of cognitive modeling illustrate the initial stages of time-consuming research into the system of the regional interregional economic and social integration. In this case, it is necessary to carry out further modeling, not only considering other possible development scenarios, but also refining and expanding the cognitive model, realizing the principle of operation on a sequence of models. It is necessary, using the methods of foresight, to propose alternative scenarios, compare them with the simulated scenarios on the cognitive model, in order to develop a strategy for the effective development of the interregional socio-economic integration for specific regions. This article outlines the path to such research.

References

1. Zgurovsky M.Z., Pankratova N.D.: System analysis: Theory and Applications. Springer, Heidelberg (2007).
2. Avdeeva Z.K., Kovriga S.V., Makarenko D.I., Maksimov V.I.: Cognitive approach to management. Management problems, 3, pp.2-8 (2007) (In Russian).
3. Kulba V.V., Kononov D.A., Kovalevsky S.S., Kosyachenko S.A., Nizhegorodtsev R.M., Chernov I.V.: Scenario analysis of the behavior dynamics of socio-economic systems. Scientific publication, M.: IPU RAS, 122 (2002) (In Russian).
4. Innovative development of socio-economic systems based on methodologies of foresight and cognitive modeling. Collective monograph, ed. Gorelova G.V., Pankratova N.D., Kiev: Naukova Dumka (2015) (In Russian).
5. Axelrod R.: The Structure of Decision: Cognitive Maps of Political Elites. Princeton, University Press (1976).
6. Casti J.: Connectivity, complexity and catastrophe in large-scale systems. Chichester-New York-Brisbane-Toronto (1979).
7. Roberts Fred S.: Discrete Mathematical Models with Applications to Social, Biological, and Environmental Problems. Englewood Cliffs N.J., Prentice-Hall (1976).
8. Eden C.: Cognitive mapping. European Journal of Operational Research, 36, pp. 1- 13 (1998).
9. Langley P.: Cognitive architectures: Research issues and challenges. Cognitive Systems Research. 10 (2)0. pp. 141-160 (2009).
10. Mehrjerdi Y. Zare: Grey theory, VIKOR and TOPSIS approaches for strategic system selection with linguistic preferences: a stepwise strategy approach. Iranian Journal of Operations Research 6 (2), 36–57 (2015).
11. Program for cognitive modeling and analysis of socio-economic systems at the regional level. Certificate of state registration of computer programs № 2018661506 (2018) (In Russian).