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Institutional Management Elaboration through Cognitive Modeling of the Balanced Sustainable Development of Regional Innovation Systems

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Abstract: The main aim of this research was to search for relevant indicators and effective instruments for modeling the impact and institutional management of the regional innovation system for its balanced development. The objective of the study was to justify approaches for institutional management elaboration for balanced sustainable development of regional innovation systems regarding related factors and the needs of the region. The methodology of cognitive modeling and scenario impulse modeling are used for the analysis of the interconnection between the regional innovation system and higher education institutions and developing an instrument to diagnose the problems of no-congruence and improving the institutional management elaboration in the regional innovation policy. The analysis of system indicators of the cognitive map allowed to define the basic patterns in the regional system, determine the most significant factors and relationships for the economic system of the region and visualize them in the form of a cognitive map, identify the influence of the innovation environment elements on the target indicators, quantify its positive and negative impact, forecast and determine the directions of its improvement and enhancing the interaction of regional actors. The results of the study have practical value for use in improving institutional management in planning reforms and transformations of regional innovation systems.

Keywords: regional innovation policy; R&D; higher education system; cognitive structuring; scenario analysis; impulse modeling; computer modeling

1. Introduction

For the dynamic innovative development of any country, not only research and development (R&D) resource support but also institutional interaction between all participants of the national innovation system is necessary. The effectiveness of the national innovation system as a set of national state, private and public organizations and the mechanisms of their interaction can be assessed from the perspective of the ability of the system to effectively carry out activities of creating and disseminating knowledge and new technologies [1–3].

Institutional management elaboration and regulation of the effectiveness of the national innovation system is located in the zone of the state innovation and regional policies and the institutional environment of innovation, which are integral parts of the innovation ecosystem.

Modern approaches based on open innovations shift the emphasis of politics towards interactions between actors of national innovation systems and consider interactive processes in the creation, diffusion, and use of knowledge. Research emphasizes the importance of the conditions, regulations, and policies under which economic systems operate, and therefore, the role of governments in monitoring and finding ways to fine-tune this entire system [4].

At the same time, the accumulation of knowledge and the stimulation of technological change through higher education in the global economy are considered important factors accelerating economic growth. The level and pace of regional territories development directly depends on human capital and the provision of needs of the region with highly qualified personnel who are able to create innovative products, services, technologies in the process of adaptation to the requirements of the regional economic system and labor market.

In this regard, in economic science and practice, a tendency has emerged to consider universities and system of higher education as full-fledged economic agents involved in economic and innovative national and regional development [5–8]. The significant role of the regional higher education system, affecting the innovative development of the regional socio-economic system, leads to the need of diagnosing the state of congruence and the relationship of these systems and searching for the most effective management tools.

The academic contribution of this research consists of using the methodology and tools of cognitive modeling and scenario impulse modeling for analysis of the interconnection between the regional innovation system and higher education institutions and developing an instrument to diagnose the problems of no-congruence and improving the institutional management elaboration in the regional innovation policy.

The objective of the study was to justify approaches for modeling institutional management elaboration for balanced sustainable development of regional innovation systems regarding related factors and the needs of the region.

The main research aim was the search for relevant effective indicators and methods for modeling the impact and institutional management of the regional innovation and higher education system, its balanced development regarding the needs of the region.

The novelty of the approach consists of the possibility to apply cognitive instruments of modeling for state policy in the field of development and regulation of the sphere of education and R&D, its reform at the regional and national levels, enhancing the interaction of regional actors, higher education institutions, public and private sectors, improving the legislative documents governing educational activities, in the development of measures for improving the regional system development of the economy.

The results are relevant for policy implications and evidence a possibility to apply developed cognitive maps for cognitive modeling of the balanced sustainable development of regional innovation systems.

The results of the study have practical value for use in developing mechanisms to improve the effectiveness of education and in assessing the effectiveness of the region system. They can be used to solve problems of improving institutional management in planning reforms and transformations of region systems.

The present work is organized as follows. The objective and main research and novelty of approach questions are in the first section. The literature review is discussed in the second section. Section three presents the theoretical framework and research methodology of cognitive modeling. Empirical results of the cognitive modeling process in the view of cognitive mapping, interrelations establishment between regional factors, analysis of “positive” and “negative” cycles of the regional system relationship and structural stability properties of the regional system are described in the fourth section. In the fifth section, we discuss the research results thorough impulse modeling of four scenarios of the balanced development of regional higher education systems in region. Finally, the last section presents conclusions and outlines some suggestions for further research.

2. Literature Review

The mechanisms and speed of the dissemination of knowledge between the actors of innovation systems determine the effectiveness of the national economy development. In today's global world, the advantages are obtained by those innovative systems that are able both to generate their own knowledge and use an external one [9]. The flexibility of regional innovation systems with respect to the diffusion of innovation allows them to be more efficient, sustainable and dynamic. Therefore, the issue of innovation diffusion processes for the sustainable development of regional economic systems is of considerable research interest.

There are many classical and modern studies investigating this issue. The theory of innovation and national innovation systems of Dosi, Freeman and Fabiani [10] shows the importance of innovation diffusion for economic growth and emphasizes the importance of coherence of national innovation system institutions in the processes of innovation diffusion. Lundvall and Nelson [11], using large empirical studies, justified the model of the national innovation system, where the firm was the main object of analysis and engine of innovation development. This approach examines the influence of external institutions on the innovation activity of the firm and other actors in the innovation system and emphasizes the importance of the processes of transfer and diffusion of ideas, knowledge and information. According to Lundvall [11], differences in technological results at the national and regional levels are significantly related to the characteristics of the institutional environment in which innovative firms are immersed, and an effective innovation system is built by the joint efforts of the state, business and scientific environment.

New roles of actors, trends and properties of the interaction between the state, science and business in the field of innovation development were analyzed by Etzkowitz and Leydesdorff [12]. They were formed in the "Triple Helix" theory, which symbolizes the union between government, business and the universities, and shows the "inclusion" in the interaction of institutions at each stage of creating an innovative product.

Hagerstrand [13], Audretsch [14], Feldman [15] and Boschma [16] investigate the diffusion of innovation as a spatial process and analyze innovation spillover effects and the geographical extent of knowledge diffusion.

A correlation between innovation input and invention output in the view of applying knowledge production function was found by Griliches [17]; it is widely used to define the impact of R&D on innovation performance at the regional level. The results of assessing geographical localization of knowledge and R&D transfer and different types of innovation are widely presented on the data of various countries by Jaffe, Trajtenberg and Henderson, Aldieri, Kotsemir and Vinci [18,19] using the models of spatial econometrics and production functions of knowledge.

The research of Brenner and Broekel [20] is devoted to the regional innovation activities and mechanisms of its influence on the regional innovation development. They analyze the influence of 70 different regional factors on the process of innovative development. Related research identifies factors that significantly affect the innovative development of the region: the presence of firms of a certain size (Stenke, Brenner and Greif), research institutions (Soete), various types of human capital (Froderer), financial resources (OECD), as well as the spillover phenomenon, cooperation, networking and interaction between various actors (Pittaway) and others [21–25].

Modern Russian literature also actively explores the processes of innovation diffusion and the impact of science, innovation and concentration of production on the economic growth of regions. Spillover effects of innovation diffusion in modern Russia are studied by Golichenko [26], which reveals the general characteristics of the innovation system, the state of innovation activity in the business environment, the production of innovative products and the impact of innovative processes on competitiveness, factors, that hinder the development of the innovative potential of the enterprise.

A detailed review of the innovation diffusion impact on the sustainable development in Russian regions was made by Aldiery Kotsemir and Vinci in [18,19], presenting deep analysis of Russian research on this subject. Using econometric modeling tools they found that " ... R&D significantly affects Russian regions productivity and that productivity spillover across regions matter" [18].

Kaneva and Untura [27] studied the impact of R&D expenditures on the growth rate of gross regional product per capita and knowledge spillover caused by spatial proximity, structure of economic activity, concentration and specialization of industries, as well as inventive activity of the population in the regions. Their calculations showed that innovatively developed regions actively financing R&D showed a higher growth rate of GRP per capita: in the resource sector—1.2 times, in the "services" sector—twice, in the "processing" sector—1.1 times compared to all regions of the country.

Zemtsov, Barinova and Muradov [28] describe important factors of regional innovation activity which are "interrelated private and budgetary expenses on R&D increase, co-location of fundamental and applied science centers, human capital quality development and the rapid development of technology transfer centers. At the same time, there are fundamental indirect factors: the level of economic diversification, the historical background of the regional innovation system development, the level of innovation development of the neighboring regions, etc. In other words, innovation activity is a multifactorial phenomenon associated with the development of regional innovation systems, which is not determined solely by the scope of R&D funding".

One of the leading Russian researchers in the spatial organization of innovation processes Pilyasov [29] has come to the conclusion that the current stage of economic development is characterized by high sensitivity to "thin" institutional factors. High-tech sectors of the economy turn out to be whimsical in relation to the local innovation environment, and it, in turn, is largely determined by institutional, cultural factors: a less energy-intensive economy is more sensitive to knowledge spillover than raw materials, and therefore it has fundamentally different placement laws.

The high importance of a stimulating and supportive environment in the region for the development of innovative activity of enterprises is emphasized in the work of Makarova and Firsova [30].

Problems of the innovation diffusion modeling in the framework of the national innovation system are researched by Zinnurova, Misbahova, Starodoubova [31]. The authors evaluated the diffusion of innovations in the Russian Federation and identified the main problems in the diffusion model of innovations, such as the lack of resources for small businesses to replicate innovations; the selection of indicators of the effectiveness of the use of investments for innovation and their assessment and management of engineering centers and their interaction between business, universities and the state.

Thus, modern Russian researchers confirm the positive impact of innovation on the region's economic growth and confirm the Lundvalls' research [11] that the national innovation system is built by the joint efforts of the state, business and scientific environment, differences in technological results at the national and regional levels can be significantly related to the characteristics of the institutional environment in which enterprises are immersed. These results necessitate the development of tools of institutional management elaboration of all actors of the innovation system.

At the same time, international researchers of national and regional innovation systems emphasize the importance of the activities of universities and regional higher education systems, and the potential mechanisms by which they can stimulate regional innovation activity are widely considered in the literature. Through the transfer of knowledge in the students' learning process, improving the quality of the workforce, university activities have spillover effect on regional innovation systems and can serve as incubators of incidental knowledge transfer. Moreover, universities play an important role in opening access to knowledge: scientific publications, seminars, symposia are also ways of transferring academic knowledge to the private sector.

The involvement of higher education in the regional economy and its contribution to the training of personnel, generation of knowledge, diffusion of innovations, formation of new technological structures and socio-economic development is considered as a new and significant factor in economic growth at the regional and national levels in all countries. The engagement of universities to the generation of innovations and transfer of knowledge at the regional level is today regarded as a significant factor in innovation growth, and the educational system is becoming the leading link in the national innovation system.

In recent decades, the issues of interaction and engagement of regional higher education systems in regional economic development and the search for the most effective mechanisms and tools for their interaction with the regions have attracted increasing attention of researchers and practitioners in developed countries and countries with developing economies.

The significant role of regional higher education systems in the socio-economic development of the region leads to the need to diagnose their organizational effectiveness and to find the most effective tools for managing them. Research and modeling of the effective proportions and relationships of the regional system of higher education and the socio-economic system of the region are aimed at achieving the optimal balance of economic interests of the parties involved. Such a balance will ensure the consistency of their actions, focus on the use of the competitive advantages of the region and increase the predictability of the expected results of interaction and integration of the regional system of higher education and the economy of the region.

The balanced development of the regional system of higher education should take into account the staffing of scientific research in the region, improving the quality of student training in educational programs of higher education taking into account the specifics of the region, involving students in scientific work and research under the guidance of research and teaching staff, using new knowledge and innovative technologies in educational, scientific and experimental activities. Modeling of the relationship of the regional higher education system and the socio-economic system of the region allows us to achieve an optimal balance of economic interests of the parties involved and to ensure the of their actions taking into account the competitive advantages of the region, as well as focusing on the predictability and consistency of the expected results of such interaction.

In such a situation, it is useful to analyze the interactions of the actors of the innovation system, the "innovation environment", partnerships, the ability to produce new knowledge in the process of educational and research activities, create and accumulate the intellectual capital necessary for the implementation of innovative activities, and the conditions for the dissemination of research results, development scientific and informational interaction in the region. The coherence of these relationships within regional partnership networks has a positive impact on the development of innovation and plays a crucial role in innovation processes.

In the case of Russia, such studies are still scarce. This article addresses this current knowledge gap. Academic contribution of the work consists in the fact that we propose using the tools of cognitive modeling to take into account such factors and to solve the problems of improving issue of institutional management elaboration in regional innovation systems.

This study focused on finding ways to balance the development of the innovation system and the higher education system in the region by building a cognitive map of the relationship between regional actors and indicators. The regional innovation system and the regional higher education system are dynamic systems that operate in a complex and unstable environment. Their peculiarity lies in the fact that they function under the influence of many factors, including qualitative, non-quantifiable factors. In such systems, networks of cause-and-effect relationships arise, which are characterized by uncertainty and ambiguity in assessing the consequences of certain decisions. Such systems are loosely structured.

One of the most effective approaches to the study of complex structured systems and processes is the methodology of cognitive modeling. It allows you to structure the factors of a complex situation or phenomenon, as well as simulate their development over time and develop scenarios for the development of events within the system and its relations with the outside world. The practical application of this method in macroeconomics, sociology, management, and other fields of activity was proposed by Roberts, Carvalho, Kosko [32–34].

Russian researchers use cognitive approach and cognitive mapping application for wide area of complex-structured systems and processes [35–39]. Cognitive modeling is using for decision making in project management, as [40]. The technique of cognitive modeling of complex socio-economic systems has been successfully tested in solving various applied problems. These works include computer modeling: of the prevention of risk situations at critical infrastructure facilities [41]; devoted to the study of poorly structured problems of socio-economic systems [42]; for the exploration of the regional development strategy [43]; of education quality management [44]; devoted to system analysis of the international activities of universities [45]; affecting the general problems of the application and development of the cognitive approach [46]; dedicated to modeling the sustainable development of the region [47], for organizational diagnostics and modeling of the enterprise [48].

There is research which has been devoted to the application of cognitive modeling methods in higher education. Motyshina and Norkin [49] suggest a method of cognitive modeling of innovation activity of institutions of higher education and described a system of factors conditioning the innovation activity. Among the factors in question they distinguish competitiveness, personnel motivation, innovation infrastructure. However, the application of cognitive modeling of the balanced development of educational and innovative systems are not so widespread, even, is almost absent and the present study is a pilot one.

This study continues the scientific discussion on regional economic development effectiveness and the search of methods and tools for assessing the modeling of quantitative and qualitative characteristics and effects and regional innovation policy. The use of cognitive modeling to build a model of the relationship between the regional system and the higher education system and the analysis of scenarios for the balanced development of regional higher education systems, applied to the needs of the region, will be aimed at preparing, analyzing and substantiating management decisions for the balanced development of regional higher education systems, which actualizes the topic of this study.

3. Theoretical Framework

3.1. Research Methodology

We used cognitive modeling for qualitative analysis aimed at increasing management efficiency in solving poorly structured problems of complex systems and contributing to the formation of a holistic picture of the problem under study.

In this section, a summary of cognitive modeling of complex socio-economic systems on a regional level is given. The construction of a cognitive model for the balanced development of regional higher education systems, meeting the needs of the region, is proposed to be implemented sequentially in the next stages.

At the first stage, a cognitive model for the balanced development of regional higher education systems, meeting the needs of the region has been developed. According to the used cognitive approach in the research process, it is necessary to develop a cognitive map of the system.

Cognitive structuring (cognitive mapping) of the selected subject area reveals future target and undesirable states of the desired control object, including the most significant control factors and exogenous factors that stimulate the transition of a given object to the identified states. Cognitive structuring also includes establishing relationships between them at the qualitative and quantitative levels, considering the relationship of the identified factors. The construction of cognitive models is based on the theory of the subject area, expert methods, statistical analysis, text analysis and other mathematical tools [50].

At the second stage, the study of the properties of a complex system of cognitive model of balanced development of regional higher education systems, meeting the needs of the region has been compiled. This stage involves: a study of the sustainability of the model of regional higher education systems development to disturbances, the structural stability of the model, ways, cycles sensitivity, complexity, connectedness, dynamics and others [50]. This stage of the study allows us to reveal in detail the nature of the connections between vertices and factors and to accumulate knowledge about the state of congruence and the relationship of the regional higher education system and socio-economic system.

At the third stage, a scenario analysis of the balanced development of regional higher education systems was performed using impulse modeling to generate possible scenarios for the development of higher education systems in the regions. At the stage of scenario analysis, hypothetical disturbing/controlling influences are added to the vertices of the cognitive map [51]. The set of development scenarios shows possible trends in the development of regional systems, taking into account the needs of the region.

The fourth stage is optional and shows correction of the cognitive model of the balanced development of regional higher education systems taking into account the needs of the region. It is performed if the model does not correspond to the real object, where the name and number of selected vertices, relations between them, impulse influences, etc. can change. Further, the refined model is additionally evaluated at stages 2 and 3.

The completion of cognitive modeling is the selection of a preferred scenario for the development of regional higher education systems taking into account the needs of the region, the development and justification of the required management decisions aimed at implementing the preferred scenario, as well as preventing the consequences of the development of undesirable scenarios.

Thus, in order to develop effective tools for managing regional interaction processes, including the preparation, analysis and justification of managerial decisions for the balanced development of regional higher education systems, it is necessary to conduct a preliminary study to identify indicators that affect the development of the regional socio-economic system, to model a complex system of regional interactions and predict possible.

3.2. Cognitive Modeling Formulas

According to the theoretical study of cognitive approach in the research process, it is necessary to develop a cognitive map of the system. The following formula of G which is a sign oriented graph (digraph) will be used:

$$G = \langle V, E \rangle \tag{1}$$

where

V is the set of vertices Vi∈V, i = 1, 2, 3, . . . , k, which are elements of the system under study;

E combines the set of arcs eij ∈ E, i, j = 1, 2, 3, . . . ,N, which reflect the relationship between the vertices Vi and Vj (positive if an increase (decrease) in one factor leads to an increase (decrease) in the other, negative, when an increase (decrease) in one factor leads to a decrease (increase) in another) [51].

The formula of the pulsed process [38] during the transition to model time in the form of simulation cycles has the form:

$$x_i(n+1) = x_{vi}(n) + \sum_{j=1}^{k-1} f_{ij} P_j(n) + Q_i(n) \tag{2}$$

where

x_i (n) the initial pulse is the value of the pulse at the vertex vi at the previous moment in time and reflects the modeling cycle (n);

x_i $(n + 1)$ represents the point of time $(n + 1)$ of interest to the researcher;

f_{ij} is the momentum conversion coefficient;

$P_j(n)$ reflects the momentum at adjacent vertices of the model;

$Q_i(n)$ is the construction of the vector of control actions and disturbances that are introduced to the vertex vi at time n.

The situation in impulse modeling of the balanced development of regional higher education systems in Russian regions is characterized by a set of all Q values and X values for each modeling step. This set of development scenarios shows possible trends in the development of regional systems, taking into account the needs of the region.

4. Results

4.1. Indicators and Cognitive Mapping

To build cognitive models of the balanced development of regional higher education systems in the regions we used 20 different regional macroeconomic indicators.

Indicators will be used to assess the relationship between the regional system and the higher education system, including indicators: the region's economy, regional production activity, research and innovation activity, the regional labor market, output, and inter-regional (international) activities, higher education systems in the region, financial indicators, federal regulatory systems, selected metrics house peer review as part of ongoing research.

Construction model of the regional system relationship for higher education system and the regional economy includes following indicators (vertices):

1. "Final consumption" vertex $V_{1,} v_1^i \in V_1, i = 1, 2, \ldots k_1$ implies innovative goods, works and services of regional enterprises and includes indicators: R&D of innovative production technologies and the volume of produced innovative goods, works, and services.
2. "Production" vertex $V_{2,} v_2^i \in V_2, i = 1, 2, \ldots k_1$ combines indicators of innovative activity of production of organizations in the region, including indicators of: volume from innovative organizations; the proportion of innovative organizations in the region; the use of specialized software in enterprises.
3. "Labor market" of the region vertex $V_{3,} v_3^i \in V_3, i = 1, 2, \ldots k_1$ the supply of labor combines the indicators of graduation by state and municipal educational organizations.
4. "Population income" vertex $V_{4,}$ constitutes an integral part of the financial system of the region, including cash flows, which determine the level of innovative production, purchasing power and living standards of the population of the region.
5. "Regional Economy" vertex $V_{5,} v_5^i \in V_5, i = 1, 2, \ldots k_1$ the economy of the region is determined by the microeconomic production function, is the connecting link of regional factors of production - labor, enterprises, resources and includes the following indicators: v_5^1: gross regional product and domestic research and development costs; v_5^2: the share of high-tech and knowledge-intensive industries in the gross regional product of the subject of the Russian Federation; v_5^3: education indicators in the industry structure of gross value added.
6. "Federal regulatory systems" vertex V_6 has an external impact on the socio-economic system of the region.
7. "National and foreign economic exchange" vertex V_7 national and international activities of the region and foreign trade activities are characterized in particular by the volume of exports and imports of innovative technology and technological product and services.
8. "Environment" vertex V_8 generalizes concept characterizing the natural conditions of a locality and its ecological state of the region.
9. "Population" vertex V_9 applies to the population of the region that has or wants and potentially can have an independent source of livelihood.
10. "Education system" the regional system of higher education is represented by vertex $V_{10,} v_{10}^i \in V_{10}, i = 1, 2, \ldots k_1$ and includes the following indicators characterizing its economic and innovative component: v_{10}^1: number of educational institutions of higher education; v_{10}^2: number of researchers with advanced degrees; v_{10}^3: income of an educational organization from all sources per one R&D worker in thousand rubles; v_{10}^4: volume of research and development income per one R&D worker in thousand rubles, university income from research and development in total university income; v_{10}^5: number of publications of organizations indexed in the scientific citation systems; v_{10}^6: number of licensing agreements of an educational organization.
11. "Investments in education" vertex V_{11} means tangible or intangible costs, the purpose of which is to profit or achieve the desired results from desired education.

12. "Level of life" vertex V_{12} is the level of material and spiritual needs satisfaction of people with a mass of goods and services in a certain period of time under certain conditions.
13. "Human capital" vertex V_{13} is an intensive productive factor in the development of regional and global economy, including the educated part of the employees, knowledge, intellectual property and working environment.
14. "Need for professionalism" vertex V_{14} is the need of enterprises (production) in professional improvement of employees.
15. "Professional and personal competences of the graduate" vertex V_{15} is the aggregate indicator for successful labor activity of future employer.
16. "Economical and political risks" vertex V_{16} shows risks arising from adverse changes in the economy of the region or in the economy of the country and risks due to changes in the political environment (national or global) affecting entrepreneurial activity of the region.
17. "Salary" vertex V_{17} is payment for work depending on the professional and personal (individual) competences of the employee, complexity, quantity, quality and conditions of work performed, as well as compensation payments and incentive payments.
18. "Supply" vertex V_{18} is production ability to provide certain quantity of products or services, including innovations of high-technology spheres in a certain period of time under certain conditions.
19. "Demand" vertex V_{19} is population need for certain quantity of products or services, including innovations of high-technology spheres in a certain period of time under certain conditions.
20. "R&D" vertex $V_{20} v_{20}^{i} \in V_{20}$, $i = 1, 2, \ldots k_1$ research and development activities of the region are aimed at obtaining an increment of knowledge and technologies and their practical application in the development and creation of innovative goods, works and services taking into account the needs of the region. "R&D" vertex includes the following indicators and information about the use of facilities intellectual property: v_{20}^{1}: number of filled and issued patent applications; v_{20}^{2}: number of patent applications in the field of high technology filed by Russian applicants; v_{20}^{3}: number of organizations performing research and development; v_{20}^{4}: research and development personnel.

A cognitive model (G) of the relationship between the regional system and the higher education system, taking into account the needs of the region, is presented in the Figure 1. It is intended to formalize the interactions of a semi-structured regional economic system. Vertices and arcs of the relationship between the regional system and the higher education system are clearly reflected. The arc-connected vertices show nonzero relationship among the regional system and the higher education system, taking into account the needs of the region. Using such cognitive map, it is possible to analyze the functioning of the regional economic system, and according to its results, it is possible to identify which vertices interactions have the strongest positive or negative impact on the indicators and relations of regional system actors. According to these results, it is possible to predict the processes' efficiency within these systems, model the behavior of the system in response to disturbing influences, and trace the effectiveness of the actors' interaction and institutional management of this system.

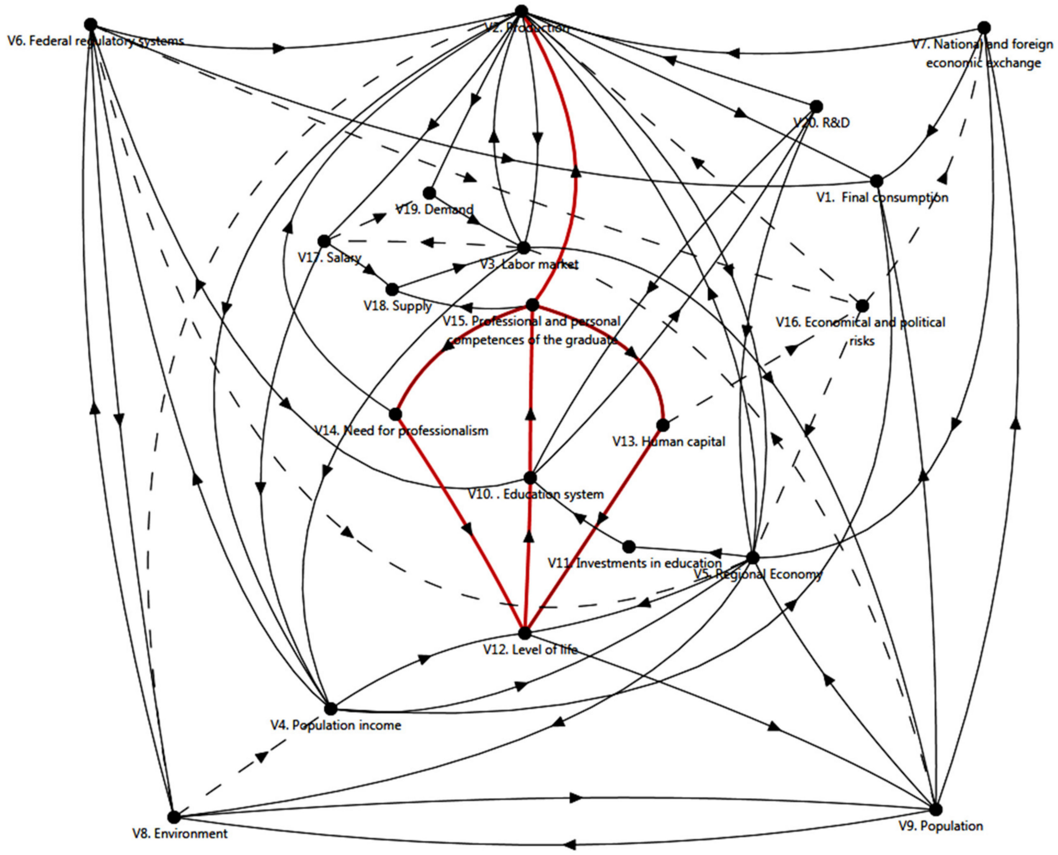


Figure 1. Cognitive model (G) of the relationship between the regional system and the higher education system, taking the needs of the region into account.

Application of the presented methodology used the unique computer program of cognitive analysis and modeling of regional socio-economic systems CMSS [52].

Moreover, in this cognitive model, it is necessary to take into account the impact of lifelong education as partnerships established in order to implement the educational function; technology transfer, as partnerships established for the implementation of the research function and social participation, as partnerships established for the implementation of the social function. These indicators take on qualitative values and reflect the relationship between the vertices of V when establishing relationships in this model.

4.2. Interrelations Establishment between Factors

The next stage is devoted to the study of the properties of a complex system of a cognitive model for the balanced development of regional higher education systems in Russian regions, taking into account the needs of the region. Figures 2–5 show particular cases of a computational experiment aimed at studying the paths and cycles of the graph of the cognitive model (G) of the relationship between the regional system and the higher education system, taking into account the needs of the region and external factors, such as federal regulatory systems, economical and political risks, and national and foreign economic exchange.

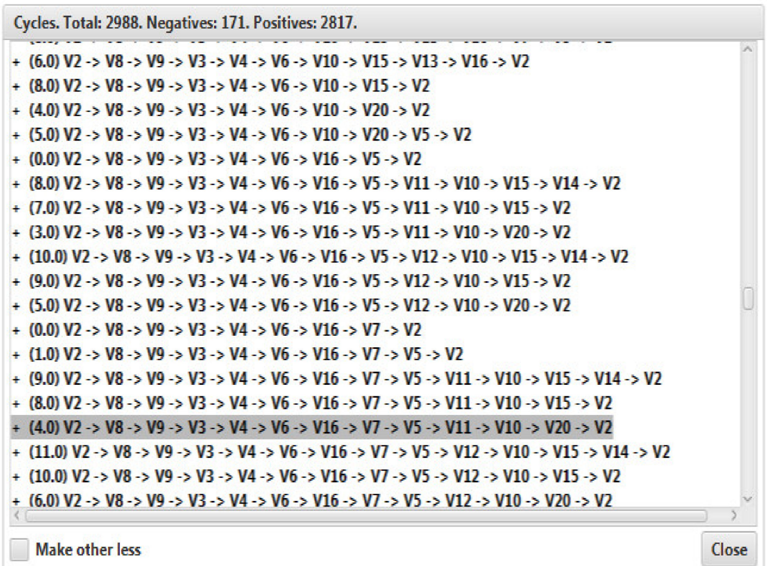


Figure 2. "Positive" cycle selection of the regional system relationship (fragment from the computer data processing results on the program CMSS).

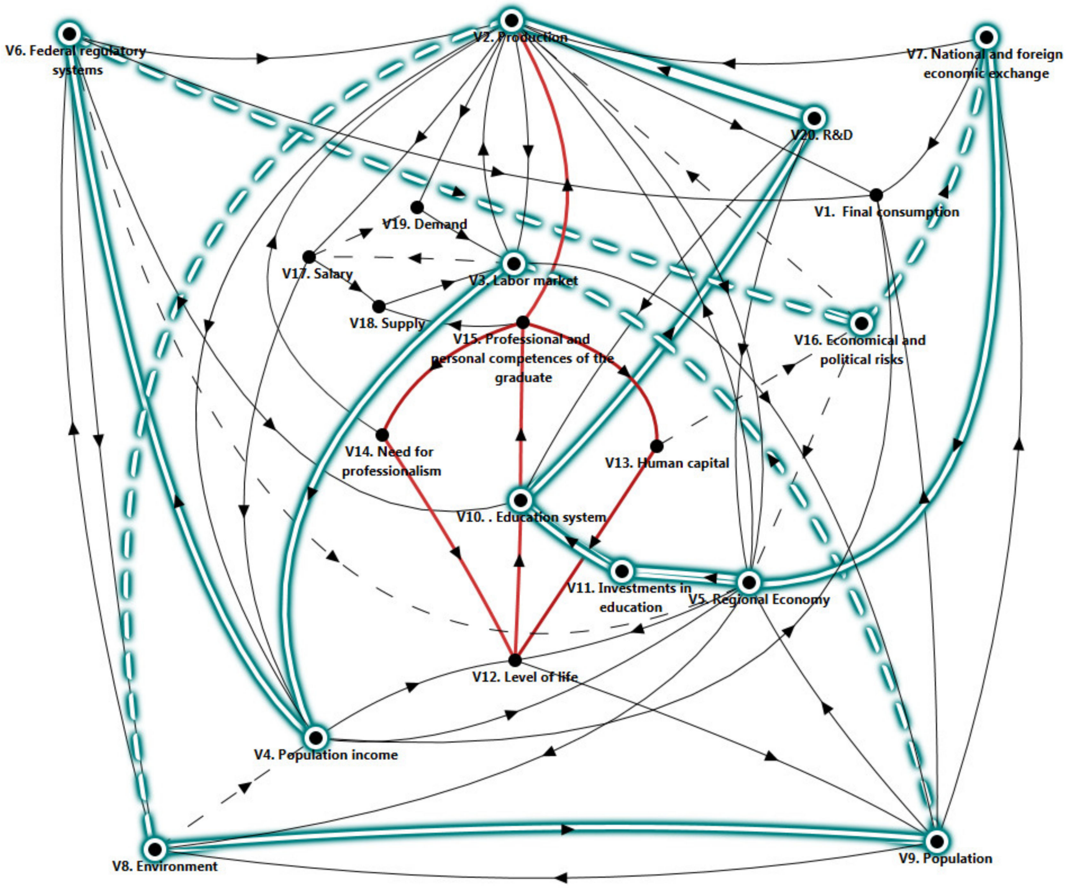
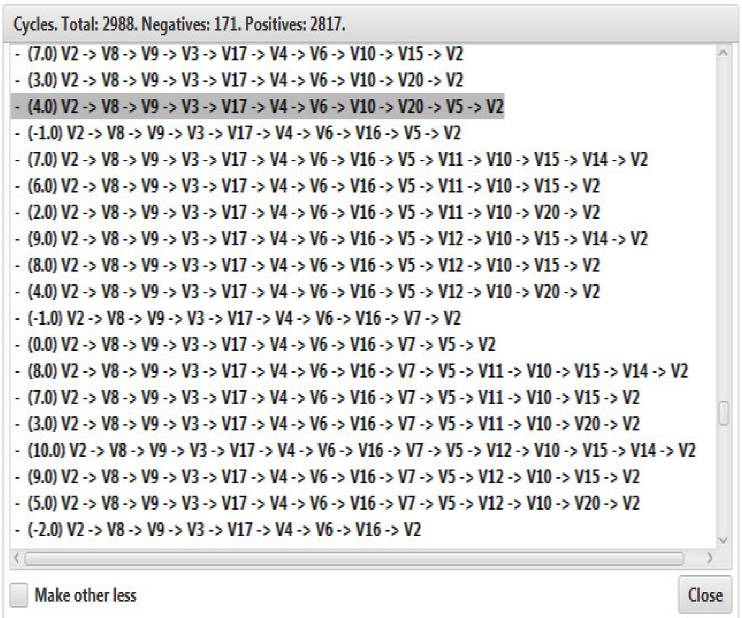


Figure 3. Highlighting (blue) the "positive" cycle of the regional system relationship.


Cycles. Total: 2988. Negatives: 171. Positives: 2817.
- (7.0) V2 -> V8 -> V9 -> V3 -> V17 -> V4 -> V6 -> V10 -> V15 -> V2
- (3.0) V2 -> V8 -> V9 -> V3 -> V17 -> V4 -> V6 -> V10 -> V20 -> V2
- (4.0) V2 -> V8 -> V9 -> V3 -> V17 -> V4 -> V6 -> V10 -> V20 -> V5 -> V2
- (-1.0) V2 -> V8 -> V9 -> V3 -> V17 -> V4 -> V6 -> V16 -> V5 -> V2
- (7.0) V2 -> V8 -> V9 -> V3 -> V17 -> V4 -> V6 -> V16 -> V5 -> V11 -> V10 -> V15 -> V14 -> V2
- (6.0) V2 -> V8 -> V9 -> V3 -> V17 -> V4 -> V6 -> V16 -> V5 -> V11 -> V10 -> V15 -> V2
- (2.0) V2 -> V8 -> V9 -> V3 -> V17 -> V4 -> V6 -> V16 -> V5 -> V11 -> V10 -> V20 -> V2
- (9.0) V2 -> V8 -> V9 -> V3 -> V17 -> V4 -> V6 -> V16 -> V5 -> V12 -> V10 -> V15 -> V14 -> V2
- (8.0) V2 -> V8 -> V9 -> V3 -> V17 -> V4 -> V6 -> V16 -> V5 -> V12 -> V10 -> V15 -> V2
- (4.0) V2 -> V8 -> V9 -> V3 -> V17 -> V4 -> V6 -> V16 -> V5 -> V12 -> V10 -> V20 -> V2
- (-1.0) V2 -> V8 -> V9 -> V3 -> V17 -> V4 -> V6 -> V16 -> V7 -> V2
- (0.0) V2 -> V8 -> V9 -> V3 -> V17 -> V4 -> V6 -> V16 -> V7 -> V5 -> V2
- (8.0) V2 -> V8 -> V9 -> V3 -> V17 -> V4 -> V6 -> V16 -> V7 -> V5 -> V11 -> V10 -> V15 -> V14 -> V2
- (7.0) V2 -> V8 -> V9 -> V3 -> V17 -> V4 -> V6 -> V16 -> V7 -> V5 -> V11 -> V10 -> V15 -> V2
- (3.0) V2 -> V8 -> V9 -> V3 -> V17 -> V4 -> V6 -> V16 -> V7 -> V5 -> V11 -> V10 -> V20 -> V2
- (10.0) V2 -> V8 -> V9 -> V3 -> V17 -> V4 -> V6 -> V16 -> V7 -> V5 -> V12 -> V10 -> V15 -> V14 -> V2
- (9.0) V2 -> V8 -> V9 -> V3 -> V17 -> V4 -> V6 -> V16 -> V7 -> V5 -> V12 -> V10 -> V15 -> V2
- (5.0) V2 -> V8 -> V9 -> V3 -> V17 -> V4 -> V6 -> V16 -> V7 -> V5 -> V12 -> V10 -> V20 -> V2
- (-2.0) V2 -> V8 -> V9 -> V3 -> V17 -> V4 -> V6 -> V16 -> V2

Make other less

Close

Figure 4. "Negative" cycle selection of the regional system relationship (fragment from the computer data processing results on the program CMSS).

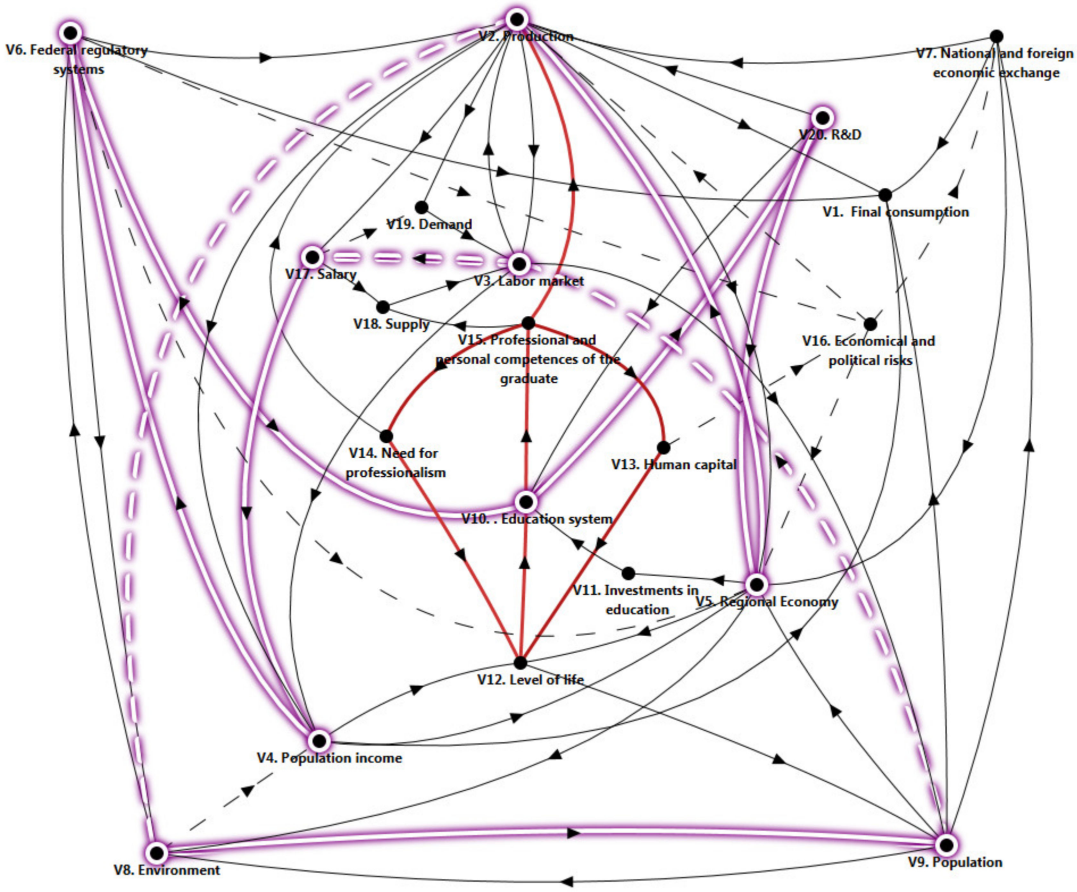


Figure 5. Highlighting (purple) the "negative" cycle of the regional system relationship.

Figure 3 visualizes the selected "positive" cycle (V2; V8; V9; V3; V4; V6; V16; V7; V5; V11; V10; V20; V2) of the regional system relationship, see fragment from the computer data processing results on the program CMSS Figure 2. Particularly, Figure 3 illustrates the selection of the "positive" cycle of the regional system relationship among production, education system, regional economy and R&D which is highlighted in blue against the background of the graph.

In turn, Figure 5 shows an example of a "negative" cycle of the regional system relationship or a cycle in which negative arcs are depicted in purple. Figure 5 visualizes the selected "negative" cycle (V2; V8; V9; V3; V17; V4; V6; V10; V20; V5; V2) of the regional system relationship, see fragment from the computer data processing results on the program CMSS Figure 4.

4.3. Structural Stability Properties of the System

The determination of the number of negative cycles is necessary for the analysis of the structural stability properties of the system. A system is structurally stable if the number of its negative cycles is odd. The cognitive model G of the relationship between the regional system and the higher education system, taking into account the needs of the region, is structurally stable, since the number of positive cycles is 2817, and negative ones—171, the number of negative cycles is odd.

Figure 6 shows the results of calculating the eigenvalues of the adjacency matrix of the cognitive model G of the relationship between the regional system and the higher education system, taking the needs of the region into account.

0	3.9403	0.0	3.9403
1	-3.5951	0.0	3.5951
2	0.0205	3.3911	3.3911
3	0.0205	-3.3911	3.3911
4	-2.3014	0.0	2.3014
5	1.7327	0.0	1.7327
6	0.0673	1.3821	1.3821
7	0.0673	-1.3821	1.3821
8	0.4491	1.2536	1.2536
9	0.4491	-1.2536	1.2536
10	-0.7422	0.6924	0.7422
11	-0.7422	-0.6924	0.7422
12	0.548	0.1753	0.548
13	0.548	-0.1753	0.548
14	-0.3051	0.0	0.3051
15	-0.1569	0.0	0.1569
16	0.0	0.0	0.0
17	0.0	0.0	0.0

Figure 6. Eigenvalues of the adjacency matrix of the cognitive model G of the relationship between the regional system and the higher education system, taking into account the needs of the region (fragment from the computer data processing results on the program CMSS).

The determination of the roots of the characteristic equation of the cognitive model G is necessary for analyzing the stability of the system to perturbations and from the initial value. In this case, the stability criterion $|M| < 1$ is used, where $|M|$ is the maximum modulus eigenvalue (root of the characteristic equation of the matrix) [53]. Since in our case $|M| = 3.9403 > 1$, the system G is not stable either to perturbation or to the initial value.

5. Discussion

As part of the next stage, we will discuss the results thorough impulse modeling and scenario modeling of the balanced development of regional higher education systems in regions. The CMSS computer program allows for pulsed simulation by introducing pulses, interpreted in accordance with the task, as "disturbing" or "control", in one or several vertices at any time at any modeling steps.

5.1. Scenario 1

To construct the selected scenario (Figure 7), let us suppose that the system is improving the state of the regional higher education system: disturbing momentum q10 = + 1; action vector Q1 = {q1 = 0; 0; q10 = + 1; 0; . . . ; 0}.

Step Vertex	0.0	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0
V2. Production	0.0	0.0	0.0	10.0	20.0	62.0	131.0	2059.0	4904.0	18259.0	48893.0	420663.0	1155050.0
V3. Labor market	0.0	0.0	0.0	0.0	13.0	33.0	29.0	100.0	2428.0	6969.0	14562.0	48956.0	477857.0
V1. Final consumption	0.0	0.0	0.0	0.0	10.0	30.0	183.0	452.0	2746.0	8359.0	43165.0	124303.0	641995.0
V4. Population income	0.0	0.0	0.0	0.0	10.0	52.0	111.0	150.0	2058.0	10377.0	28794.0	70679.0	474362.0
V5. Regional Economy	0.0	0.0	0.0	1.0	11.0	41.0	192.0	554.0	2747.0	10181.0	45550.0	145669.0	660737.0
V6. Federal regulatory systems	0.0	0.0	0.0	0.0	0.0	1.0	43.0	150.0	353.0	972.0	9287.0	32860.0	100267.0
V7. National and foreign economic exchange	0.0	0.0	0.0	0.0	0.0	9.0	68.0	118.0	330.0	2385.0	13685.0	32329.0	111095.0
V9. Population	0.0	0.0	0.0	0.0	0.0	59.0	99.0	269.0	714.0	11172.0	23644.0	85464.0	250952.0
V8. Environment	0.0	0.0	0.0	0.0	-9.0	-9.0	39.0	203.0	-1086.0	-1090.0	4066.0	29588.0	-156670.0
V10. . Education system	0.0	1.0	1.0	2.0	2.0	169.0	240.0	857.0	1816.0	31255.0	58831.0	251232.0	654466.0
V11. Investments in education	0.0	0.0	0.0	0.0	1.0	11.0	41.0	192.0	554.0	2747.0	10181.0	45550.0	145669.0
V12. Level of life	0.0	0.0	0.0	0.0	55.0	75.0	201.0	411.0	9830.0	17765.0	66836.0	172408.0	1904118.0
V13. Human capital	0.0	0.0	0.0	9.0	9.0	18.0	18.0	1521.0	2160.0	7713.0	16344.0	281295.0	529479.0
V14. Need for professionalism	0.0	0.0	0.0	9.0	9.0	18.0	18.0	1521.0	2160.0	7713.0	16344.0	281295.0	529479.0
V15. Professional and personal competences of the graduate	0.0	0.0	3.0	3.0	6.0	6.0	507.0	720.0	2571.0	5448.0	93765.0	176493.0	753696.0
V16. Economical and political risks	0.0	0.0	0.0	0.0	-9.0	-9.0	-19.0	-61.0	-1671.0	-2513.0	-8685.0	-25631.0	-314155.0
V17. Salary	0.0	0.0	0.0	0.0	10.0	7.0	29.0	102.0	1959.0	2476.0	11290.0	34331.0	371707.0
V19. Demand	0.0	0.0	0.0	0.0	10.0	10.0	55.0	102.0	1957.0	2945.0	15783.0	37603.0	386332.0
V18. Supply	0.0	0.0	0.0	3.0	3.0	16.0	13.0	536.0	822.0	4530.0	7924.0	105055.0	210824.0
V20. R&D	0.0	0.0	1.0	1.0	2.0	2.0	169.0	240.0	857.0	1816.0	31255.0	58831.0	251232.0

Figure 7. Scenario "Improving the conditions of higher education system in the region" disturbing momentum q10 = + (fragment from the computer data processing results on the program CMSS).

Figures 8 and 9 show the results of impulse modeling according to a scenario simulating the effect of improving the state of the regional higher education system via the processes in the socio-economic system of the region, the impulse arrives at one vertex.

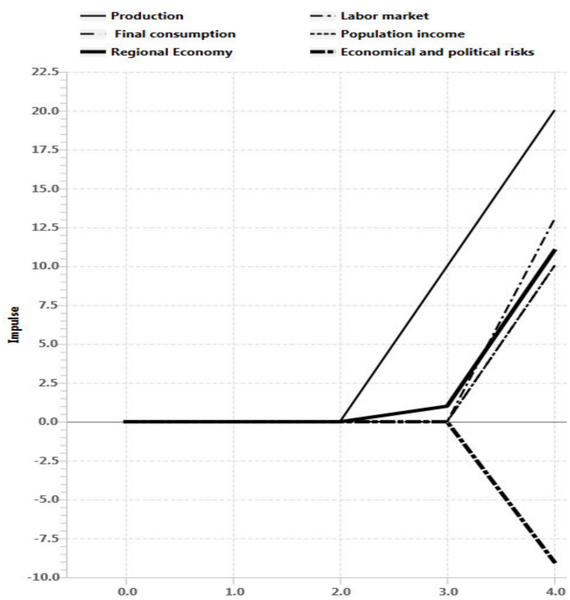


Figure 8. The graph of impulse processes at the selected vertices V1–V5, V16 Scenario "Improving the conditions of higher education system in the region" disturbing momentum q10 = + 1.

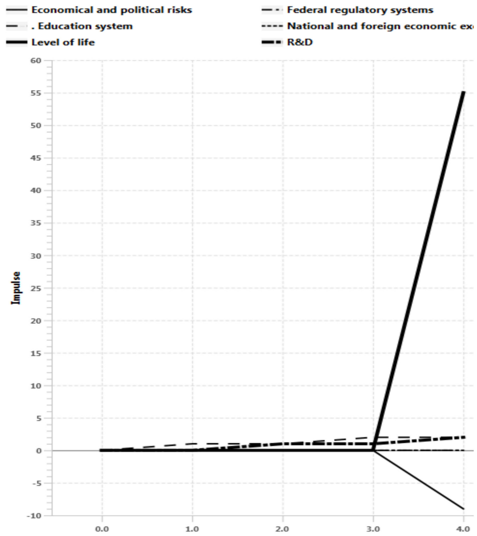


Figure 9. The graph of impulse processes at the selected vertices V6, V7, V10, V12, V16, V20 Scenario " Improving the conditions of higher education system in the region" disturbing momentum q10 = + 1.

Scenario 1 results. The analysis of Figure 5 shows that improving the conditions of the regional higher education system after the second step leads to an increase in production indicators, labor market, final consumption, population income, finance and the economy of the region as a whole, and after $n > 2$, especially rapid growth of all factors is observed. Figure 7 indicates conditions of the regional higher education system after the third step $n > 3$ leads to rapid growth for level of life indicator, but stable situation in indicators of federal regulatory systems, national and foreign economic exchange, and R&D, at the same time rapid decrease of economic and political risks can be observed.

5.2. Scenario 2

To construct the selected scenario (Figure 10), let us suppose that the transformations begin in the education system. corresponding to the requirements of modern society; managing influence q10 = + 1., but at the same time political and economic risks increase q16 = + 1; action vector Q1 = {q1 = 0; 0; . . . ; q10 = + 1; 0; . . . ; q16 = + 1; 0; . . . ; 0}.

Step Vertex	0.0	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0
V2. Production	0.0	0.0	-1.0	7.0	14.0	49.0	60.0	1784.0	3965.0	15403.0	34032.0	361984.0	934398.0
V3. Labor market	0.0	0.0	0.0	-1.0	9.0	26.0	18.0	25.0	2085.0	5960.0	11744.0	32920.0	407630.0
V1. Final consumption	0.0	0.0	0.0	-2.0	5.0	15.0	142.0	316.0	2286.0	6484.0	36546.0	97098.0	539485.0
V4. Population income	0.0	0.0	0.0	-1.0	5.0	40.0	92.0	76.0	1650.0	8832.0	24313.0	52012.0	386123.0
V5. Regional Economy	0.0	0.0	-1.0	-2.0	5.0	27.0	155.0	426.0	2253.0	8157.0	38178.0	116536.0	546720.0
V6. Federal regulatory systems	0.0	0.0	0.0	0.0	-1.0	-4.0	28.0	117.0	277.0	627.0	7762.0	27520.0	83081.0
V7. National and foreign economic exchange	0.0	0.0	-1.0	-1.0	-1.0	6.0	58.0	91.0	227.0	1858.0	11830.0	26393.0	87275.0
V9. Population	0.0	0.0	0.0	0.0	-2.0	51.0	78.0	218.0	365.0	9826.0	19161.0	71576.0	174108.0
V8. Environment	0.0	0.0	0.0	0.0	-9.0	-12.0	25.0	201.0	-1023.0	-1070.0	3207.0	31069.0	-146352.0
V10. . Education system	0.0	1.0	1.0	2.0	-2.0	153.0	192.0	734.0	882.0	27730.0	46576.0	213525.0	442632.0
V11. Investments in education	0.0	0.0	0.0	-1.0	-2.0	5.0	27.0	155.0	426.0	2253.0	8157.0	38178.0	116536.0
V12. Level of life	0.0	0.0	0.0	-1.0	51.0	64.0	175.0	139.0	8764.0	14271.0	56625.0	110119.0	1665968.0
V13. Human capital	0.0	0.0	0.0	9.0	9.0	18.0	-18.0	1377.0	1728.0	6606.0	7938.0	249570.0	419184.0
V14. Need for professionalism	0.0	0.0	0.0	9.0	9.0	18.0	-18.0	1377.0	1728.0	6606.0	7938.0	249570.0	419184.0
V15. Professional and personal competences of the graduate	0.0	0.0	3.0	3.0	6.0	-6.0	459.0	576.0	2202.0	2646.0	83190.0	139728.0	640575.0
V16. Economical and political risks	0.0	1.0	1.0	1.0	-8.0	-7.0	-13.0	-9.0	-1493.0	-2004.0	-7232.0	-15699.0	-277089.0
V17. Salary	0.0	0.0	0.0	-1.0	8.0	5.0	23.0	42.0	1759.0	1880.0	9443.0	22288.0	329064.0
V19. Demand	0.0	0.0	0.0	-1.0	8.0	6.0	44.0	37.0	1742.0	2206.0	13523.0	24589.0	339696.0
V18. Supply	0.0	0.0	0.0	3.0	2.0	14.0	-1.0	482.0	618.0	3961.0	4526.0	92633.0	162016.0
V20. R&D	0.0	0.0	1.0	1.0	2.0	-2.0	153.0	192.0	734.0	882.0	27730.0	46576.0	213525.0

Figure 10. Scenario "Improving the conditions of higher education and economical and political risks increasing" disturbing momentum q10 = + 1 and q16 = + 1 (fragment from the computer data processing results on the program CMSS).

Figures 11 and 12 show the results of impulse modeling according to a scenario simulating the effect of improving the state of the regional higher education system via the processes in the socio-economic system of the region and economical and political risks increasing, the impulse arrives at two vertices.

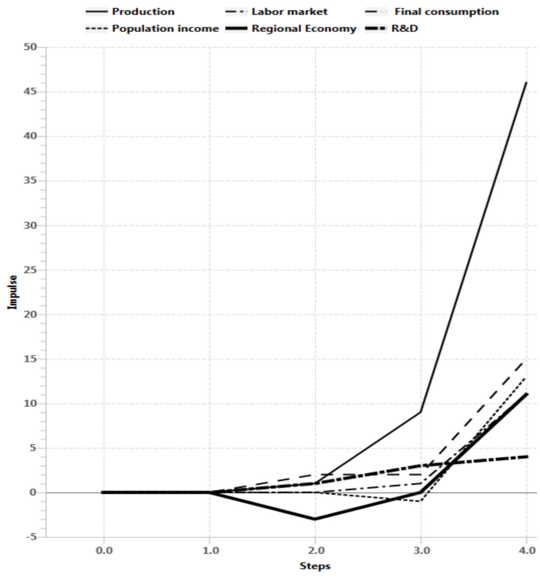


Figure 11. The graph of impulse processes at the selected vertices V1–V5, V20 Scenario "Improving the conditions of higher education and economical and political risks increasing" disturbing momentum q10 = + 1 and q16 = + 1.

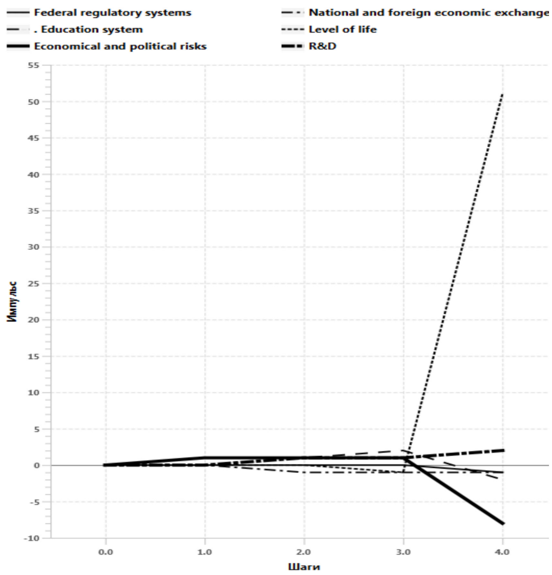


Figure 12. The graph of impulse processes at the vertices V6, V7, V10, V12, V16, V20 Scenario "Improving the conditions of higher education and economical and political risks increasing" disturbing momentum q10 = + 1 and q16 = + 1.

Scenario 2 results. The analysis of "Improving the conditions of higher education and economical and political risks increasing" scenario shows unsustainable situation of the socio-economic situation of the region (Figure 11), where in long term prospective only after the third step $n > 3$ slowly leads to an increase in production indicators, labor market, final consumption, population income, regional economy and R&D sphere. At the same time, Figure 12 indicates steady conditions for the regional indicators of federal regulatory systems, national and foreign economic exchange, education system, R&D, and after $n > 3$, a sharp increase of level of life due to higher education influence. This scenario shows unsustainable situation of the socio-economic situation of the region without long term development.

5.3. Scenario 3

To construct the selected scenario (Figure 13), let us suppose that the transformations begin in the education system. corresponding to the requirements of modern society; managing influence q10 = + 1., but at the same time political and economic risks increase q16 = + 1 which are opposed by the actions of federal regulatory systems q6 = + 2; action vector Q1 = {q1 = 0; 0; . . . ; q6 = + 2; 0; . . . ; q10 = + 1; 0; . . . ; q16 = + 1; 0; . . . ; 0}.

Step / Vertex	0.0	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0
V2. Production	0.0	0.0	1.0	9.0	46.0	103.0	184.0	2106.0	8765.0	27201.0	67762.0	475602.0	1870280.0
V3. Labor market	0.0	0.0	0.0	1.0	11.0	68.0	100.0	61.0	2275.0	11956.0	28142.0	56412.0	512502.0
V1. Final consumption	0.0	0.0	2.0	2.0	15.0	57.0	252.0	760.0	3438.0	12438.0	56500.0	188968.0	823853.0
V4. Population income	0.0	0.0	0.0	-1.0	13.0	68.0	246.0	274.0	1942.0	13484.0	49755.0	110570.0	524439.0
V5. Regional Economy	0.0	0.0	-3.0	0.0	11.0	75.0	249.0	910.0	3423.0	14373.0	61154.0	216670.0	866838.0
V6. Federal regulatory systems	0.0	2.0	2.0	4.0	-1.0	12.0	30.0	293.0	585.0	1545.0	9378.0	50336.0	157767.0
V7. National and foreign economic exchange	0.0	0.0	-1.0	1.0	3.0	8.0	86.0	261.0	497.0	2408.0	17648.0	58083.0	156261.0
V9. Population	0.0	0.0	0.0	2.0	-4.0	61.0	214.0	504.0	649.0	11862.0	44425.0	129262.0	320248.0
V8. Environment	0.0	0.0	2.0	-2.0	-3.0	-40.0	45.0	309.0	-399.0	-4108.0	579.0	47195.0	-79334.0
V10. . Education system	0.0	1.0	3.0	4.0	-4.0	163.0	578.0	1346.0	1958.0	32800.0	116658.0	358175.0	878072.0
V11. Investments in education	0.0	0.0	0.0	-3.0	0.0	11.0	75.0	249.0	910.0	3423.0	14373.0	61154.0	216670.0
V12. Level of life	0.0	0.0	0.0	-3.0	53.0	186.0	359.0	279.0	9986.0	36577.0	100541.0	216641.0	2098440.0
V13. Human capital	0.0	0.0	0.0	9.0	27.0	36.0	-36.0	1467.0	5202.0	12114.0	17622.0	295200.0	1049922.0
V14. Need for professionalism	0.0	0.0	0.0	9.0	27.0	36.0	-36.0	1467.0	5202.0	12114.0	17622.0	295200.0	1049922.0
V15. Professional and personal competences of the graduate	0.0	0.0	3.0	9.0	12.0	-12.0	489.0	1734.0	4038.0	5874.0	98400.0	349974.0	1074525.0
V16. Economical and political risks	0.0	1.0	-1.0	-1.0	-12.0	-25.0	-47.0	7.0	-1759.0	-5786.0	-13658.0	-26999.0	-345535.0
V17. Salary	0.0	0.0	0.0	1.0	8.0	35.0	35.0	84.0	2045.0	6490.0	15245.0	39620.0	419190.0
V19. Demand	0.0	0.0	0.0	1.0	8.0	38.0	68.0	149.0	2022.0	6720.0	20711.0	52517.0	435982.0
V18. Supply	0.0	0.0	0.0	3.0	10.0	20.0	23.0	524.0	1818.0	6083.0	12364.0	113645.0	389594.0
V20. R&D	0.0	0.0	1.0	3.0	4.0	-4.0	163.0	578.0	1346.0	1958.0	32800.0	116658.0	358175.0

Figure 13. Scenario "Improving the conditions of higher education and economical and political risks increasing, while federal regulatory system actions are taken" disturbing momentum q6 = + 2, q10 = + 1 and q16 = + 1 (fragment from the computer data processing results on the program CMSS).

Figures 14 and 15 show the results of impulse modeling according to a scenario simulating the effect of improving the state of the regional higher education system via the processes in the socio-economic system of the region and economical and political risks increasing, while actions of federal regulatory systems are taken, the impulse arrives at three vertices.

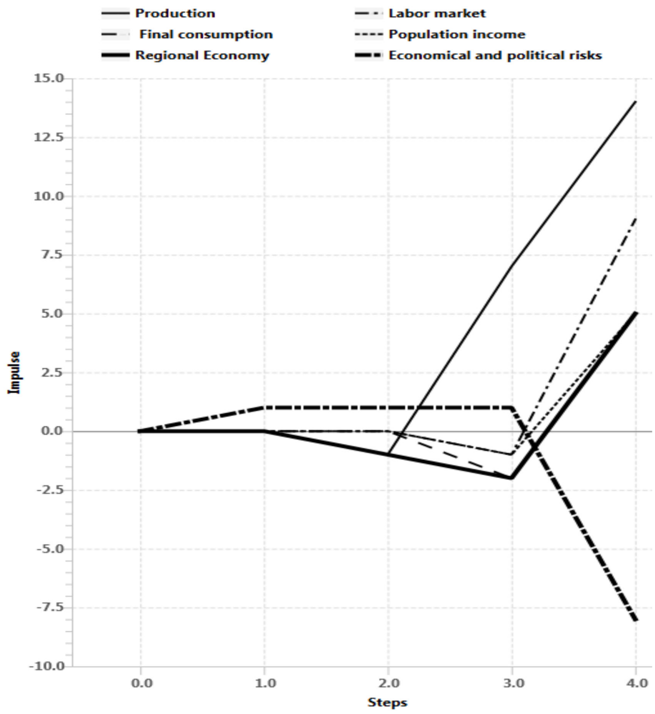


Figure 14. The graph of impulse processes at the selected vertices V1–V5, V16 Scenario "Improving the conditions of higher education and economical and political risks increasing, while federal regulatory system actions are taken" disturbing momentum q6 = + 2, q10 = + 1, q16 = + 1.

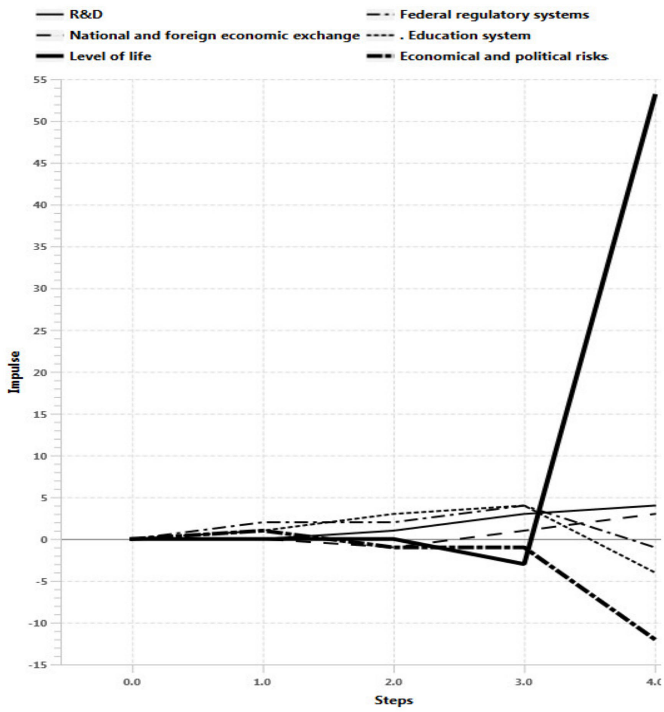


Figure 15. The graph of impulse processes at the selected vertices V6, V7, V10, V12, V16, V20 Scenario "Improving the conditions of higher education and economical and political risks increasing, while federal regulatory system actions are taken" disturbing momentum q6 = + 2, q10 = + 1, q16 = + 1.

Scenario 2 results. Improving the conditions of higher education and economical and political risks increasing, while federal regulatory system actions are taken, leads to unsustainable situation of the region in long term prospective ($n > 3$), including labor market decrease, regional economy, final consumption and labor market gaps (Figure 14). At the same time, there is an overall decrease in indicators of federal regulatory systems, education system, national and foreign economic exchange and R&D, at the same time the level of life growth is explained as a result of federal regulatory system actions (Figure 15).

5.4. Scenario 4

To construct the selected scenario (Figure 16), let us suppose that there are transformations beginning in the education system that meet the requirements of modern society; managing influence q10 = + 1., but at the same time political and economic risks q16 = + 1 are increasing, which are opposed by the actions of federal regulatory systems q6 = + 1 and R&D increasing q20 =+1; action vector Q1 = {q1 = 0; 0; . . . q6 = + 3; 0; . . . q10 = + 1; 0; . . . ; q16 = + 1; 0; . . . ; q20 =+1}.

Step Vertex	0.0	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0
V2. Production	0.0	0.0	1.0	10.0	44.0	105.0	246.0	2289.0	9150.0	28336.0	81887.0	513634.0	1997706.0
V3. Labor market	0.0	0.0	0.0	1.0	13.0	64.0	99.0	140.0	2555.0	12120.0	28996.0	73180.0	565297.0
V1. Final consumption	0.0	0.0	1.0	1.0	13.0	57.0	256.0	827.0	3667.0	13728.0	59979.0	208305.0	886374.0
V4. Population income	0.0	0.0	0.0	0.0	13.0	72.0	232.0	349.0	2291.0	14416.0	50692.0	125471.0	598813.0
V5. Regional Economy	0.0	0.0	-1.0	1.0	13.0	72.0	270.0	961.0	3785.0	15643.0	65588.0	235545.0	943073.0
V6. Federal regulatory systems	0.0	1.0	1.0	2.0	0.0	8.0	41.0	270.0	635.0	1730.0	10776.0	52321.0	166364.0
V7. National and foreign economic exchange	0.0	0.0	-1.0	0.0	1.0	9.0	88.0	263.0	563.0	2906.0	18535.0	60447.0	173392.0
V9. Population	0.0	0.0	0.0	1.0	-1.0	62.0	220.0	496.0	1089.0	12591.0	46415.0	134501.0	399048.0
V8. Environment	0.0	0.0	1.0	-1.0	-6.0	-32.0	37.0	285.0	-562.0	-3641.0	1628.0	40892.0	-91267.0
V10. . Education system	0.0	1.0	3.0	4.0	3.0	172.0	590.0	1367.0	3124.0	34759.0	122449.0	372811.0	1095288.0
V11. Investments in education	0.0	0.0	0.0	-1.0	1.0	13.0	72.0	270.0	961.0	3785.0	15643.0	65588.0	235545.0
V12. Level of life	0.0	0.0	0.0	-1.0	55.0	188.0	360.0	664.0	10598.0	37936.0	103877.0	284976.0	2238002.0
V13. Human capital	0.0	0.0	0.0	9.0	27.0	36.0	27.0	1548.0	5310.0	12303.0	28116.0	312831.0	1102041.0
V14. Need for professionalism	0.0	0.0	0.0	9.0	27.0	36.0	27.0	1548.0	5310.0	12303.0	28116.0	312831.0	1102041.0
V15. Professional and personal competences of the graduate	0.0	0.0	3.0	9.0	12.0	9.0	516.0	1770.0	4101.0	9372.0	104277.0	367347.0	1118433.0
V16. Economical and political risks	0.0	1.0	0.0	0.0	-10.0	-26.0	-43.0	-67.0	-1817.0	-5944.0	-14032.0	-38891.0	-365151.0
V17. Salary	0.0	0.0	0.0	1.0	9.0	31.0	41.0	147.0	2149.0	6595.0	16216.0	52891.0	440454.0
V19. Demand	0.0	0.0	0.0	1.0	9.0	35.0	74.0	205.0	2142.0	7001.0	21741.0	65671.0	460743.0
V18. Supply	0.0	0.0	0.0	3.0	10.0	21.0	40.0	557.0	1917.0	6250.0	15967.0	120493.0	420238.0
V20. R&D	0.0	1.0	2.0	4.0	5.0	4.0	173.0	591.0	1368.0	3125.0	34760.0	122450.0	372812.0

Figure 16. Scenario "Improving the conditions of higher education and economical and political risks increasing, while federal regulatory systems and R&D reacting" disturbing momentum q6 = + 1, q10 = + 1 and q16 = + 1, q20 =+1 (fragment from the computer data processing results on the program CMSS).

Figures 17 and 18 show the results of impulse modeling according to a scenario simulating the effect of improving the state of the regional higher education system via the processes in the socio-economic system of the region and economical and political risks increasing, while federal regulatory systems and R&D reacting, the impulse arrives at four vertices.

Scenario 4 results. Improving the conditions of higher education and economical and political risks increasing, while federal regulatory systems and R&D reacting shows the sustainable development of the regional system in long term prospective. There is a stabilization phase in the second step (Figure 17), which leads to rapid growth of production indicators, labor market, final consumption, population income, finance and the economy of the region as a whole after $n > 3$. At the same time analysis of impulse processes of graph (Figure 18) also shows sustainable situation of the regional with R&D development, including federal regulatory systems growth and economical and political risks decrease in long term prospective.

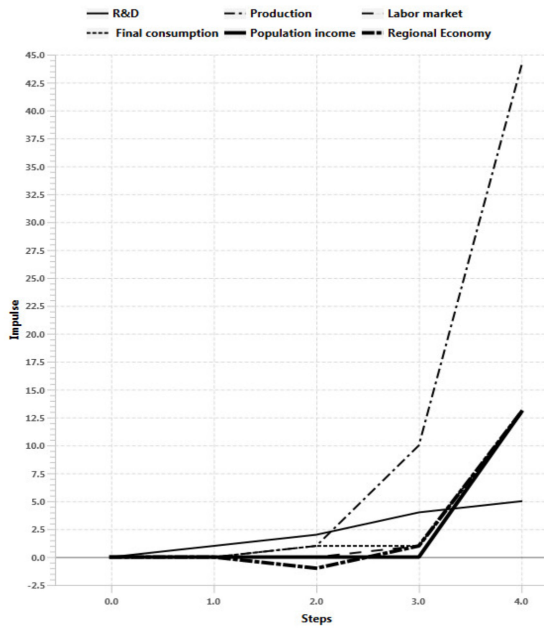


Figure 17. The graph of impulse processes at the selected vertices V1–V5, V20 Scenario "Improving the conditions of higher education and economical and political risks increasing, while federal regulatory systems and R&D reacting" disturbing momentum q6 = + 1, q10 = + 1 and q16 = + 1, q20 =+1.

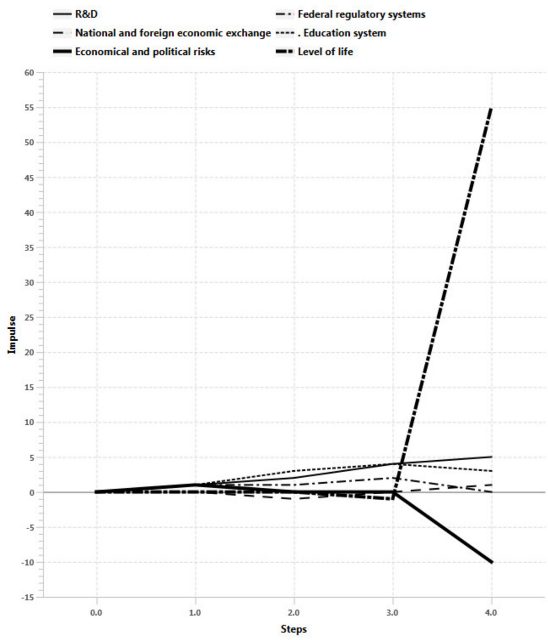


Figure 18. The graph of impulse processes at the selected vertices V6, V7, V10, V12, V16, V20 Scenario "Improving the conditions of higher education and economical and political risks increasing, while federal regulatory systems and R&D reacting" disturbing momentum q6 = + 1, q10 = + 1 and q16 = + 1, q20 =+1.

6. Conclusions

Modern approaches to regional innovative development shift the emphasis of politics towards improving interactions between actors in the economic system and consider interactive processes in the creation, dissemination and use of knowledge as a driver of innovative development. The importance of the conditions, regulations and policies under which economies operate is increasing, and therefore, so is the role of government policies in monitoring and finding ways to fine-tune this entire system.

Thus, the study presents the possibilities of cognitive modeling of complex socio-economic systems, provided by software tools that facilitate the research process of describing and understanding the features of their functioning and can be successfully used to predict development scenarios and substantiate management decisions by regional experts.

In the study, the results of diagnostics of the state of congruence in the balanced development of regional institutions were obtained. It is shown that cognitive modeling allows analyzing and justifying managerial decisions aimed at the balanced development of regional systems, taking into account the specific needs of the region.

The resulting cognitive model allows evaluating the balanced development of the socio-economic systems taking into account the needs of a particular region using the tools of impulse modeling and scenario analysis. Carrying out such a preliminary experiment using a simulation model is often the only possible way to calculate the consequences of changes in making management decisions, compared with the cost of conducting an experiment on a real object.

Modeling the relationship of the regional institutions and the socio-economic system of the region allows achieving an optimal balance of economic interests of the parties, involved and ensuring consistency of their actions taking into account the competitive advantages of the region including R&D, as well as predictability and consistency of the expected results of such interaction.

The analysis of system indicators (vertices of cognitive model) of the cognitive map allowed to define the basic laws of the observed situation in the regional system; determine the vertices and the most significant factors and relationships for the economic system of the region and visualize them in the form of a cognitive map; identify the influence degree of the innovation environment elements on the target factors of the system vertices; model and quantify the degree of positive and negative impact on the innovative development of the region and the higher education system, the change in the strength or direction of influence, the possibility of creating new contours of influence and connections between vertices and there may even be new actors that increase or decrease the dissonance of the system and increase its effectiveness innovation development; make a forecast of the situation development for the analyzed innovation system and determine the main directions of its improvement.

The presented methodology for managing the regional innovation process can be used to forecast development scenarios and justify managerial decisions, allows testing the influence of various factors and substantiating management decisions on improving institutional management in planning reforms and transformations of region systems.

The model allows you to solve the problem of making decisions on process management in a situation to provide the desired changes in the target factors. The decision maker can not only track the transitions of his model from state to state, but also evaluate the "stability" or "convergence" of each alternative. It helps to simulate the controlled development of the regional economic system by assessing the consequences of the influence factors as a subject to control influences and quantify the strength of this impact. The problems of strategic management and decision support in the field of regional innovation development, for which traditional research methods are ineffective, can be solved using the model we presented.

Validation of the model is assessed by experts, its adoption by users to model the decision-making situation, as well as a qualitative and quantitative comparison of the model (economic system) reaction to the input disturbing effects and reactions of the real economy in the process of its use and the correspondence of the model forecasts to the specific needs of users and the real situation in the economy. This finding could be important in terms of policy implications of developing a policy for managing the regional innovation system and processes. Using the proposed model will improve the reliability and quality of the analysis and modeling of problems in semi-structured systems and processes in the face of uncertainty.

The implementation of the formulated conclusions, concepts, developed approaches and methods will provide an integrated approach to the analysis and evaluation of the effectiveness of regional systems. It is consists in the possibility of using the state policy in the field of development and regulation of the educational and R&D sectors, its reform at the regional and national levels, and enhancing the interaction of regional subjects, higher education institutions, public and private sectors, improving legislative documents governing the educational activities, the development of measures to improve the education and R&D regional sectors for the development of the national economy.

However, we can identify some limitations in the methodological approach of our research. The results obtained during the analysis of the presented cognitive maps should not be exaggerated, since in essence this method should be considered as a tool for supporting managerial decision-making in the regional system. The presented model is the first stage of express analysis as a test option for determining the relationships and the impact of impulses. When choosing strategic decisions in regional politics, it is certainly necessary to repeatedly test and adjust the model, as well as use a wide range of tools for assessing the region's innovative capabilities.

Further development of the cognitive approach to the study of the Russian economy will provide effective tools for making forecasts and for substantiating decisions to manage emerging problem situations. In perspective, it is planned to conduct studies and build scenarios for the development of the regional system and the higher education system based on the constructed cognitive map taking into account the needs of a particular region of the Russian Federation. It would be interesting to extent the vertexes and explore particular regional system. An analysis of the development scenarios for the regional higher education system, taking into account the needs of a particular region, will allow developing weighted management decisions for the balanced development of the selected regional system.

Moreover, the application of the cognitive modeling method to assess and develop measures of institutional management elaboration is a rather flexible and effective tool for supporting decision-making in strategic areas of regional economic development. The effectiveness of the cognitive method application is significantly increased when the actors making decisions on the innovation development policy in the region have real leverage for the operational impact on the simulated system, since significant intellectual and material resources are spent on the preparation of decision-making.

Further studies of the dynamics of the cycle influence of several factors (model vertices) on the system of innovative and higher education will be in the following areas: create an effective model of the functioning of the innovative regional mechanism, predict and simulate the behavior of the system under several development scenarios, contribute to the adoption of informed decisions on the strategic areas of activity of the higher education system and the innovation system of the region, and create recommendations for improving institutional management in transformations of regional higher education systems, including R&D sphere.

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