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Models and Methods of Formation of the Foresight-Controlling Mechanism

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Abstract: The necessity of mechanisms for long-term forecasting and regulation of high-tech enterprise development strategies has been determined. This paper discusses how managers and designers can create models and methods for sustainability management mechanisms. The elements of novelty of this study and contribution to the existing theory of managing objects of socio-economic systems are: the development of the principle of a single mechanism of foresight-controlling, which made it possible to increase the efficiency and sustainability of the organizational behavior of objects; the development of theoretical and methodological models for the formation of a foresight-controlling management mechanism; the improvement of the management mechanism based on the combined application of mechanical and organic models of organizational behavior of socio-economic systems; the development of methods for regulating the management mechanism according to stability criteria in accordance with the characteristics of the enterprise's innovation cycle; finally, the modernization of mathematical models and methods for studying the processes of functioning of the control mechanism. The following results of the implementation of the methods at the enterprise-object of research were obtained: the assessment and adjustment of planned and target indicators of the quality of management were carried out on the basis of an examination of the parameters of the quality of regulation; recommendations were developed for adjusting the planned and target indicators of the quality of the formation of development strategies, taking into account the factors of the knowledge economy. The results' validations were implemented in projects and plans for the innovative development of the facility based on the transformation factors of the 5–6th modes of the economy.

Keywords: integration and combination of resources; mechanism of foresight-controlling; development strategies; organizational design

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1. Introduction

1.1. Substantiation of the Relevance and Concept of Scientific and Design Research

The relevance of the formation of a management mechanism for the integration of resources is growing in the context of the transformation of organizational and technological modes (OTM) of the economy. This is necessary to meet its needs to regulate transformations of objects in a system of socio-economic type (industrial enterprises, educational, scientific and design organizations, hereinafter called objects). It is necessary to design organizational processes for integrating functionals and combining foresight and controlling subsystems in a single mechanism. This substantiated the multiparametric concept of developing methods of theory and management methodology to improve the procedures for assessing the quality parameters of regulating the interaction of systems using diversified resources in a complex. Therefore, the concept of harmonizing interests by regulating the processes of integration and combination of enterprise resources with the high-tech potential of education and modern science objects is proposed. The feasibility of integrating their resources follows from the growing needs for the development of society on a postindustrial basis. The predominantly industrial domestic economy is so far

distinguished by the predominant share of production of homogeneous exchange-traded commodities of the raw type, controlled by their consumers. The classification that has developed in theory and practice classifies such an economy into the 2–3rd modes. Such conditions correspond to the 4th OTM and are confirmed by statistical data for the period 1980–2020 year [1–5]. The lag behind the regions of the world that use the factors of the knowledge economy in the conditions of the 5th or 6th modes is especially great.

1.2. Goals, Methods and Applications of the Results of the Study

At the same time, in domestic practice, the possibilities of combining, replacing and diversifying the resources of innovative transformations of objects in the context of the transformation of the OTM economy are not sufficiently taken into account. This is manifested by the low efficiency of the use of poorly diversified resources of individual enterprises outside the system. In conditions of low integration of resources, the absence of a mechanism for the integration of resources and insufficient innovation of the results of transformations, the problems of innovative transformations of objects and methods of reducing or eliminating problems of environmental and management content are relevant. This requires a methodology for integrating diversified resources and special technologies for its regulation.

It is necessary to develop models of the theory and a unified methodology mechanism of management, justifying the integration-balancing orientation toolkit with predictive-controlling properties of enterprise sustainability regulation proposed by one of the authors of this article [5,6]. They proposed the name of the mechanism: "Foresight-Controlling Resource Integration" (FCIR). Therefore, the purpose of this study is to develop models of the theory and methodology for improving the methods of organizational design of the processes of integrating knowledge economy resources in a single FCIR mechanism for predicting goals based on the results of monitoring the environment and periodically monitoring the quality factors of managing the sustainability of the innovative development of the object under study in the formed complex of objects. Digital models of the regulators of the mechanism should be specialized according to the stages of the innovation cycle of the object of study in order to improve the accuracy of estimates and adjust the planned and target indicators of the quality of management and their forecasts. The results of the examination of the parameter estimation coefficients should be verified on the basis of mathematical models of digital simulators of mechanism regulators. Recommendations for assessing and adjusting the planned and target quality indicators for the factors of the 5–6th modes of the knowledge economy should determine the organizational, behavioral and economic indicators of the sustainable functioning of the enterprise-object of research.

Methods of organizational design of the FCIR mechanism are proposed to be implemented in the concept and context of special procedures for integrating functionality and combining foresight and controlling subsystems in a single mechanism. In order to stabilize the balance of efficiency and innovation indicators, it is necessary to specify the procedures for developing models and functions for the formation of the FCIR mechanism, coordinating the goals of innovative development and monitoring environmental factors at the stages of decomposition, analysis and synthesis of the mechanism in the system analysis methodology. It is expedient to model the coordination of interests of enterprises in the complex of objects of the knowledge economy in digital simulators of the processes of regulating their interaction in the system of regional agglomeration. To improve the quality of processes, it is necessary to develop additional specific management functions (CFCs). Together with standard functions and quality parameters, they can form an innovative system of balanced indicators for the sustainable development of enterprises across the complex and the region. They can be recommended by the newly organized Center for Digital Coordination of Interests (hereinafter referred to as the Center) of the objects of the complex for the development of planned strategies and investment projects of enterprises as part of a regional cluster, taking into account the facts of the knowledge economy. The relevance of combining the principles of mechanistic and organic design models in the

concept of coordinating the interests of innovative development of objects according to specialized sustainability criteria is substantiated [6]. The recommendations of the Center can increase the possibility of coordinating the interests of objects in a large system for managing the integration and combination of resources of a regional cluster of a high-tech knowledge economy. The concept defines methods of organizational design using forecasts of normative coefficients of management quality to adjust plans and strategies for high-tech interaction of objects in terms of the sustainability of innovative development.

Organizational design was carried out in accordance with the principles of centralization and decentralization of powers. The functioning of the foresight-controlling mechanism of the enterprise was carried out in the context of increasing the possibilities for making effective management decisions to improve the structure, coordination and control of the processes of interaction between the enterprise and the facilities of the complex in the analog–digital platform of the Center. The place for validation of the results of the study was chosen as an enterprise of the machine-building industry. The relevance of the organizational design of the proposed management mechanism was determined by the fact that at the initial stage of transformation, it was in the conditions of the 3–4th modes of the industrial-type economy [5]. The choice of a medium-sized facility with a standard number of employees (approximately 1500 people), the production of products with high added value, but insufficient innovation, made it possible to solve the typical problems of reducing competitiveness and demand. This determined the growing importance of high-tech transformations of similar enterprises in terms of factors of the 5–6th modes.

2. Literature Review/Background

2.1. Methods of the Theory and Methodology of Managing the Integration of Resources

In the period 1948–2021, there was an increase in the number of publications in science on new methods for assessing the sustainability and effectiveness of innovative development of complex socio-economic and technical systems (Table 1). Until 2013, the theoretical and methodological foundations of mathematical modeling of the processes of cyclic development of complex systems were created. Separate accounting of VUCA factors of the external and internal environment and ease of accounting were shown, but the use of methods for controlling goals and for the foresight of indicators of innovative development were not shown. Evaluation of the effectiveness of short-term projects for the evolutionary development of an enterprise outside the complexes and without coordinating interests with the objects of the knowledge economy was also created [7–15]. In the period of 1980–2005, practical results of applying the methods for developing economic and mathematical models of sustainability and economy of development appeared according to the conditions of equilibrium and balance of interests of individual objects of systems. Display of evolutionary and spasmodic processes and the possibility of modeling physical and technical processes that are radically different in speed were shown, but the lack of economic and managerial applications of methods was apparent. Modeling of jump-like processes in the cycles of physical dynamics of natural phenomena, operation of technical devices, representation of processes and technologies were present. Joint consideration of external and internal factors, the possibility of regulating efficiency according to the criteria of balance of interests and sustainability of the cyclical development of the enterprise were modeled, but the coordination of its relationships with the objects of the knowledge economy according to the efficiency factors of innovative development was not modeled. Models have been developed for determining strategic plans for the long-term development of complex socio-economic and technical systems according to innovativeness factors and sustainability criteria within an individual enterprise or region and country [2,16–22]. In the subsequent period of analysis of the genesis at stages 4 and 5, the works of other scientists were developed. Separate use of foresight and controlling subsystems of enterprise development trends and the possibility of using the criterion of sustainability of high-tech development in knowledge economy systems were present, but there were no specific functions for integrating and combining resources of knowledge economy objects

consistent with standard enterprise management functions. Mainly financial models of evolutionary increases in innovativeness of development based on foresight management in the "triangle of knowledge" or controlling strategic goals have been developed, and principles of building a controlling system and evaluating its effectiveness have been proposed [1–6,14,23–33] and appeared, increasing the cyclical and strategic opportunities for improving the quality of managing the forecasting and for controlling the environment. The use of convergent models of cross-functional integration of enterprises with objects of the knowledge economy and the possibility of achieving stability in bifurcation processes of increasing the efficiency of innovative development were present, but the control subsystem of the enterprise and the complex became more complicated. A method of joint consideration of factors of the external and internal environment is proposed, which increases the creativity of the processes of innovative development. New specific functions for integrating and combining knowledge economy resources are implemented in a single foresight-controlling mechanism.

Table 1. Theoretical model of the methodology for the formation of the mechanism for foresight-controlling of goals and factors of enterprise development.

Element 1	Element 2	Element 3
Decomposition of the goals of the functioning of the mechanism in the procedures for diagnosing factors and opportunities for integrating and combining enterprise resources and complex	Analysis of the quality of functions, structures and relationships of enterprises with the objects of the complex for development procedures of additional features and mathematical models	Synthesis of models, structures and parameters of the quality-of-functioning mechanism in the procedures for modeling the efficiency of enterprise-development processes
1.1. Expansion of the composition of factors of the internal and external environment: IVUCA + EVUCA enterprises that affect the cost-effectiveness of innovative development in the complex of objects of the knowledge economy	2.1. Development of an additional function for integrating resources and quality parameters of its coordination in combination with standard enterprise management functions	3.1. Modeling the processes of integration of resources by the effects of functions and quality parameters on improving the efficiency of enterprise development
1.2. Evaluation of the possibilities of integrating functions and combining enterprises with objects of the knowledge economy. Distribution of enterprises by stages of the innovation cycle and degree of inclusion in the complex	2.2. Development of an additional function for combining resources and quality parameters for its coordination in combination with standard enterprise management functions by cycle stages	3.2. Modeling the processes of combining resources by the effects of functions and parameters on improving the efficiency of the innovative development of an enterprise in cycles
1.3. Evaluation of the effectiveness of the separate application of the subsystems of controlling and foresight of the speed and efficiency of the innovative development of an enterprise outside the complex	2.3. Development of an additional function for controlling the speed of impacts on the quality parameters of integration and combination functions in the complex and enterprise	3.3. Development of the structures of the foresight-controlling mechanism for the economic development goals of the enterprise and the Digital Coordination Center based on Big Data and Data Science tools
1.4. Creation of an analog–digital platform for regulating the efficiency of innovative development of enterprises in the structure of the Center of the complex and the use of a single mechanism for foresight-controlling	2.4. Application and interpretation of mathematical models of generalized and step functions to assess the efficiency of evolutionary and spasmodic processes of enterprise development in the innovation cycle	3.4. Evaluation and planning of the parameters of preventive effects of target and factor indicators of functions on the economic development of the enterprise by stages of the innovation cycle

Source: developed by the authors.

An analysis of the genesis of the methods allows us to draw conclusions about the need to combine existing and new approaches to monitoring environmental factors. It is required to improve the theoretical and methodological foundations for regulating the relationships of enterprises in comparison with the indicated sources of information by

methods of integrating and combining resources in a complex of objects of the knowledge economy with the formation of special management mechanisms.

2.2. Methods of High-Tech Development of Enterprises in Terms of Efficiency and Sustainability

The analysis of the genesis of the theoretical and methodological foundations of the study of the processes of innovative development of enterprises, carried out in paragraph 2.1 of the study, made it possible to proceed to the assessment of more modern scientific results. The concepts of managing the development of enterprises by methods of regulating their spatial integration are especially relevant in assessing the results of innovative development under the conditions of uncertainty of environmental factors [1–5].

With regard to the indicated types of structures, the fifth level of the pyramid corresponds to the 1–3rd OTMs, the 4th to the 4th OTMs. The author considers the creation of innovative technological principles to be the highest level: they cause the emergence of new stereotypes of thinking, creative behavior and network structures aimed at high technologies of management, education or production. They also call it a technology for shaping public consciousness, "tech-hume", for high-tech development, "high-tech". The stability of the effective dynamics of the application of these technologies is determined by the stability of the processes of transformation of enterprises and organizations in the space and time of transformation of structures. The concept of sustainability has many aspects and includes the characteristics of the economy, management, ethical–aesthetic, social, environmental, technological and other aspects [23,27,28].

In the period 2008–2021, the subsystems of separate controlling of regulatory goals and foresight of the studied properties of sustainability, efficiency and innovation prevailed [25,33,34]. It has been established that high-tech development in a crisis and taking into account the standard understanding of VUCA factors of the external environment are effective when integrating their characteristics to better account for the resources of the knowledge economy. This is numerically confirmed by the correlation between managerial competencies, the quality of knowledge management and creative thinking by modeling the processes of effective functioning of knowledge networks in a number of studies [5,31,35,36]. Estimates of the foresight of future employment in the field of science, technology and innovation as a spiral of innovation in various configurations of the "knowledge triangle" were obtained [25,35–37]. There is also a lack of knowledge of such forms of organizing the interaction between science and education for the innovativeness of the functioning of the enterprise [30,31,38]. This determines the special role of higher education in the framework concept of the "triangle of knowledge" in improving the efficiency of regulating reverse flows of knowledge. Coordination tools are needed to ensure the balance of interests of the objects of a complex system. Such interaction serves as a methodological basis for the integrated application of other concepts of high-tech development ("third mission", "triple helix", "four-link helix", "entrepreneurial or socially oriented university", "smart specialization") [36].

In modern conditions of revolutionary innovative transformations, there are processes of either an exponential or abrupt and singular kind. Therefore, ensuring stability is a prerequisite for an object in such processes during the transition from the state of the 3–4th OTMs according to the factors of the 5–6th modes. This is manifested in the contradiction between the limited degree of diversification of natural resources and its unlimited capabilities when integrating the resources of these objects into the complex being formed. Consequently, there is a need to improve the quality of management of the consistency of the impact of factors of transformation of structures on the sustainability of processes of innovative transformations of objects in terms of sustainable development of society. A special organization of interaction is required in a complex of enterprises and organizations with a diversified composition of resources.

Epstein and Roy propose a stable structure that will allow managers to identify the driving forces of the enterprise, affecting productivity [17]. They developed a model and presented an analytical, multicriteria approach to assessing how businesses should meet

the challenges of sustainable development [27]. Reefke and Trocchi consider the issues of ensuring sustainability using the example of supply chain management: they propose a balanced set of scorecards as well as the processes of their development and implementation to assess efficiency [32]. At the same time, the task of forming and regulating quality indicators of management of innovative transformations of a separate object according to the criteria of stability of internal and external processes of interaction with other objects of the complex remains not completely solved in the absence of a special mechanism for managing the integration of their resources.

Research on economic sustainability is related to modeling based on statistical analysis. Indeed, low- and medium-tech innovations in the field of intellectual labor and capital, assessed in an industrial-type economy only by the return on their assets, do not correspond to the challenges of the postindustrial knowledge economy. This is manifested in the contradiction between the limited integration and diversification of the competence resources of the innovative transformations of individual employees and the growth of their capabilities when integrating resources in the facilities of the complex or project groups.

Communication even on individual trajectories of studying the needs of industry and using the capabilities of universities in the knowledge economy provide multidisciplinary in solving complex problems. Such inclusion of personnel in the processes of acquiring new competencies is possible in an expanded space of competencies by combining the capabilities of high-tech and tech-hume technologies. In this study, the specified characteristics of competencies are proposed to be implemented in the virtual space of a network of objects in the formed mechanism FCIR for managing the integration of their resources. It should be included in the structure of a special body regulating joint activities of objects. Continuous regulation of direct and feedback links should provide targeted impacts on the degree of cooperation or inclusion of educational institutions, science, enterprises and individual project groups in the virtual complex. The integration of their resources is achieved by combining organizational analog and digital methods to reduce the techno-humanitarian imbalance using high-tech, tech-hume and foresight technologies.

The imperfection of models and methods for assessing the efficiency and speed of the transition of enterprises from low-tech levels of the industrial economy leads to the choice of scenarios such as "creative destruction". The processes of elimination of obsolete technologies or their minor modernization by individual VUCA factors prevail. Such regulation based on deviations from the results of only operational control reduces the circle of supporters of long-term scenario planning. In conditions of environmental uncertainty and crises, foresight methods are needed to predict the sustainable high-tech development of objects [6,30,31,38]. It is necessary to take into account risky complex alternatives aimed at radical changes in the complex of technologies. Therefore, the use of new methods for representing development trends and normative forecasts for the development of complex systems is spreading [31].

There is a need for coordinated organizational and economic impacts of management subsystems on the economic sustainability of social and technological collaborations [5,6,24]. This substantiated the relevance of the development of theoretical and methodological foundations of integration-balancing management of high-tech system transformation processes based on the emerging FCIR mechanism [3,4,6]. At the stage of its functioning, it is necessary to develop methods for integrating and combining the capabilities and resources of digital controlling and foresight in a single mechanism.

3. Resource Integration Management Mechanism Models

3.1. Theoretical and Methodological Models for the Formation of the Foresight-Controlling Mechanism

The complex composition of the system under study and the need to coordinate the sustainable interaction of its objects determine the development of a theoretical model and the development of a methodology for managing the processes of integration and combination of resources of the knowledge economy of a regional agglomeration in the

authors' theoretical research model. It is represented by three elements of the system analysis methodology (Table 1).

The initial research procedures are represented by element 1 of decomposition of the goal into subgoals and activity functions to isolate the object of research from the environment and diagnose their separate functioning outside the complex. Element 2 is disclosed by the procedures for analyzing standard and additional functions for managing the interaction of enterprises as part of the complex being formed. The content of element 3 of the theory is shown by the methods of synthesis of a single FCIR mechanism and the procedures for the functioning of its digital simulator, set forth in the methodological part of the study.

The element of decomposition of the goals of the functioning of the mechanism for improving the quality of regulation of the efficiency and sustainability of the development of an enterprise in the complex of objects of the knowledge economy makes it possible to determine the input factors and specify the directions for analyzing the structures of an enterprise [3,4]. The integration of factors of the external and internal environment for their monitoring and regulation is substantiated [5,6]. Procedures 1.1–1.4 for diagnosing the problems of an enterprise in the innovation cycle are proposed. The cycle is presented in the authors' convergent model of the integration-balancing management methodology for stages 1–4 of the innovation cycle [5,6]. Factors of the external environment influencing the speed and time of changes in patterns (Vy, t) are taken into account. This determines managerial decisions to regulate the rate of increase in the efficiency of innovative development of enterprises Vp (Figure 1). The new mechanism should contribute to minimizing imbalances in the goals of efficiency and innovation that arise in critical zones A, B and C of the cycle.

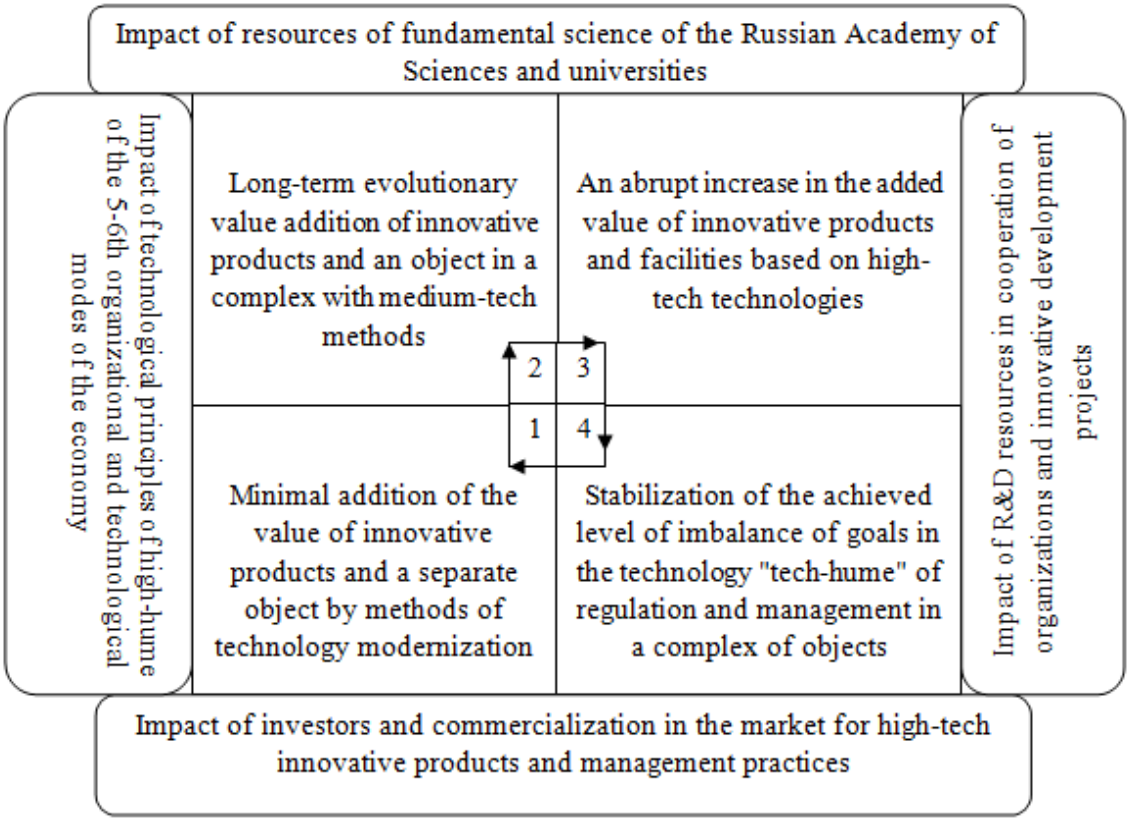

Figure 1. Conceptual analog model of resource integration management by factors of transformation of organizational and technological modes of the economy and the criterion of economic sustainability (Source: developed by the authors).

The study proposes an addition to the standard form of accounting for VUCA factors when integrating two types of environmental characteristics according to the formula "IVUCA + EVUCA". Such a combination of functions for accounting for internal and external factors forms a subsystem for monitoring enterprises. The influence of the external macro- and microenvironment of the economy on the complex is shown by arrows of four types (External). These takes into account the following characteristics: volatility (volatility), uncertainty (uncertainty), complexity (complexity) and ambiguity (ambiguity). Internal (Internal) types of factors (IVUCA) take into account the consistency of the interaction of subsystems of each enterprise under the influence of the "tech-hume" environment of the complex: assessment by personnel of the goals of strategic development as part of the complex; perception by the staff of the vision of joint development in the complex (vision); understanding the goals of innovative development (understanding); clarity of representation of a situation of conflict of interest (clarity); flexibility of decisions based on the continuous study of the possibilities of innovative development (agility).

The decomposition element 1.2 of the procedure is necessary to assess the potentials for integrating functions and combining resources in the interaction of enterprises with the objects of the complex. When moving to stages 2–4 of the innovation cycle, procedure 1.3 is carried out, substantiating the potential for integrating functionals and combining subsystems of controlling and foresight at stages 1 and 2 of the analog model of the integration-balancing regulation methodology [5]. Procedure 1.4 revealed that even the high intensity of the use of standard management functions of separately operating enterprises at stages 1 and 2 ensures the efficiency of only the processes of modernizing technologies and management methods. In the new structure of the Center of the complex during this period, it is necessary to form design and research teams of experts and consultants to develop subsystems and functionality of the FCIR mechanism. To improve the quality of regulation of the high-tech innovative development of enterprises (stage 3) and their stabilization at stage 4, Big Data and Data Science digital tools can be developed and applied.

The content of element 2 is an analysis of the possibilities in the procedures for determining the necessary functions, methods, indicators and direct and feedback links of the new mechanism. Links are provided by the use of standard enterprise management functions in conjunction with additional CFUs based on the algorithmic scheme of the FCIR mechanism, which is developed below. This led to the modernization of the concepts of economic sustainability of the innovative development of an enterprise in the context of convergence of the goals of resource integration. Therefore, new types of the basic concept of sustainability are proposed which are specialized for individual stages of the innovation cycle: the functional type of UUf—for the modernization of standard management functions and technologies of separately functioning enterprises according to the factors of the internal environment (stage 1); structural SLM—to take into account the expanded composition of environmental factors and develop quality parameters for regulating the functions of integration, combining resources and the speed of their impacts (stage 2); bifurcation VUb—to ensure a nonequilibrium state in zones A, B and C and variability of development trends (quadrant 3); economic and organizational CUE—ensuring the stabilization of the trade-off of the efficiency of the innovative development of the enterprise in the short and long term (stage 4).

3.2. Models and Methods for Studying the Processes of Formation of the Foresight-Controlling Mechanism

It is proposed to consider the authors' models of the theory and methodology for the formation and functioning of a single FCIR mechanism as a scientific contribution to the development of the theory of agglomeration management. The complexity of the inter-relations of the emerging socio-economic system of the complex in the agglomeration determined a multiparameter approach to substantiating the target parameters of the quality of regulation based on the results of monitoring the factors of the external and internal environment. An increase in the consistency of the goals of enterprises in the system was

achieved by methods of developing and making decisions in the system of organizational design of KFU [4]. To reduce the delay in response to changes in the environment, it is proposed to use three additional CFUs: the speed of impacts of the functions of managing the integration and combination of resources; the integration of resources for high-tech innovative development of enterprises in the complex; the combination of innovative resources of the complex for high-tech development of enterprises.

Planning and implementation of additional KFU mechanisms is carried out by special parameters of regulatory quality indicators. The efficiency of the use of resources for the innovative development of an enterprise is the output (resulting) variable $H_n(x)$. The arguments of the three indicated functions are taken to be the coefficients for estimating the parameters of the quality of regulation of the effects of input variables, denoted by x_i (where $i = 1, \ldots, n = 15$ is the number of regulation parameters). The quality indicators of the application of functions are distributed over the ranges of the L. Harrington function (very low, low, etc.) [31]. Their purpose is determined by the ranges of compliance of the degree of personnel focus with the characteristics of the stage of the enterprise's innovation cycle, which are disclosed below. The structure of the proposed economic efficiency vector of the innovative development of an enterprise $H_n(x)$ corresponds to a multiparameter approach to organizing the effects of the mechanism regulators on the CUE level.

The parameters necessary for assessing the actual and planned impacts of the indicators of each function are proposed to be set on the basis of arithmetic average estimates of chiav., presented by 15 experts from among specialists in the new structure of the Center of the complex. Five ranges were used in assessing the intervals of the shares of a single (de) segment, characterizing a very high (1–0.8), high (0.8–0.63), medium (0.63–0.37), low (0. 37–0.2) and very low (0.2–0) degree of influence of the parameters on the approximation to a certain quality ideal in the indicated verbal–numerical scale. The objectivity of the estimates was tested in the presence of initial training recommendations from experts using pattern recognition methods in fuzzy sets.

In the control subsystem for regulating the parameters of the quality of development of an enterprise, three groups are formed below the functional dependencies given below (Table 2) of this result on the quality factors for managing the integration of resources—KUi ($x_{i\text{cp}}.$); their combination—KUK ($x_{i\text{cp}}.$); and the speed of the impact of the first two functions—Kus ($x_{i\text{cp}}.$) = $\frac{\mathrm{d}H_i(x_i)}{\mathrm{d}x_i}$. The efficiency vector components have the form (1):

$$\overline{H} = \text{KU}i\left(x_{i\text{cp}}.\right),\ \text{Kuk}\left(x_{i\text{cp}}.\right),\ \text{Kus}\left(x_{i\text{cp}}.\right) \tag{1}$$

Table 2. Additional control functions and quality parameters of multiparameter regulation of the processes of integration and combination of knowledge economy resources of a convergent type.

Options	Names of management functions and coefficients for assessing the quality parameters of regulating the speed and efficiency of the innovative development of an enterprise in the complex of objects of the knowledge economy
Integration scores	1. Management of the integration of resources of high-tech innovative development of an enterprise in the complex by regulating the coefficient of the average assessment of the total impact of the quality parameters of the regulation of the processes of integration of innovative resources: KUi ($x_{i\text{cp}}.$) = $x_{1\text{cp}}. + x_{2\text{cp}}. + x_{3\text{cp}}. + x_{4\text{cp}}. + x_{5\text{cp}}./5$
x_1	The degree of manifestation of innovative competencies of researchers and developers of enterprises and facilities of the complex to generate creative ideas; readiness to resolve conflicts in a team
x_2	The degree of flexibility of the structures of the objects of the complex based on the results of estimates of the number of design and research groups, the possibility of delegation of authority and the absence of negative facts of "group thinking"

Table 2. *Cont.*

x_3	The degree of application of information technologies based on Big Data and Data Science tools in monitoring IVUCA + EVUCA factors of the internal and external environment such as "tech-hume" and "high-tech" on the scale of the complex, country and world
x_4	The degree of use of methods and regular procedures for assessing risks when making decisions on options for high-tech development of enterprises in the complex
x_5	The degree of use of innovative methods for the implementation of creative ideas in a team formed taking into account the differences in the competencies of researchers and developers of projects for high-tech development of enterprises in the complex
Combination estimates	2. Management of the combination of innovative resources of the complex for the high-tech development of the enterprise by adjusting the coefficient of the average estimate of the total impact of the quality parameters of the regulation of the processes of combining innovative resources: KUK($x_{i\text{cp}}$.) = $x_{6\text{cp}}$. + $x_{7\text{cp}}$. + $x_{8\text{cp}}$. + $x_{9\text{cp}}$. + $x_{10\text{cp}}$./5
x_6	The degree of awareness of researchers and developers about the possibilities and results of high-tech development of enterprises in the complex of objects of the knowledge economy
x_7	The degree of interconnectedness of enterprises and facilities of the complex, taking into account the EVUCA factors of the external environment of the "high-tech" type
x_8	The degree of readiness and abilities of researchers and developers for self-learning; exchange of experience between enterprises and facilities of the complex based on trainings in teams of joint innovative development projects
x_9	The degree of awareness of managers and specialists of the goals and development strategies when monitoring IVUCA + EVUCA environmental factors on the scale of the complex, the country and the world
x_{10}	Availability and effectiveness of permanent procedures for selecting candidates for filling vacancies from among researchers and developers of enterprise development projects in the complex
Speed ratings	3. Controlling the speed of impacts of the functions of managing the integration and combination of resources for the innovative development of an enterprise by adjusting the coefficient of the averaged assessment of the impacts of the quality parameters of process regulation by the speed of impacts of the functions of integration and combination of innovative resources: KUs($x_{i\text{cp}}$) = $x_{11\text{cp}}$. + $x_{12\text{cp}}$. + $x_{13\text{cp}}$. + $x_{14\text{cp}}$. + $x_{15\text{cp}}$./53
x_{11}	The degree of interest of business leaders in accelerating the promotion of innovative ideas of researchers based on the efficiency of adjusting goals when monitoring opportunities and threats in the environment
x_{12}	The degree of efficiency of managers in the operational assessment of the situation of development of enterprises while monitoring environmental factors to promote innovative ideas and the formation and development of teams in innovative development projects
x_{13}	The rate of perception by the personnel of enterprises of the vision, mission, goals and new norms and values of the organizational culture of high-tech development when monitoring the IVUCA + EVUCA factors of the internal and external environment of the complex, such as "tech-hume"
x_{14}	The speed of providing feedback on the results of the innovative development of enterprises and the work of their cross-functional and interdisciplinary teams in the development of a development strategy with the participation of top-level managers and the recommendations of the Complex Center
x_{15}	The degree of focus and efficiency of management in ensuring the advanced development of competencies of innovative susceptibility of the personnel of enterprises based on their training in the skills of working as agents of change (without the involvement of external consultants)

Source: developed by the authors.

Procedure 2.1 of the analysis element (see Table 1) was applied to develop an additional KFU-1 integration of resources and quality parameters. The Center recommends that quantitative assessments of the impact of parameters be carried out using the coefficient KU*i* ($x_{i\text{cp}}$.), determined by the averaged sum of the parameters of the quality of regulation in the range (x_1–x_5).

Procedure 2.2 for developing additional CFU-2 combining resources, object structures and quality parameters for its coordination with standard enterprise management functions is designed to form or modernize enterprise structures. Such structures should ensure interaction with the objects of education and science. The application of the function is regulated by the coefficients KUK ($x_{i\text{cp}}$.). They are determined by the averaged sum of the regulation quality parameters in the range ($x_6 - x_{10}$) of the efficiency of the innovative development of the enterprise in the complex.

It was revealed that the resulting property of economy depends on the degree of formalization of the organizational behavior of the elements of the system [4,36,37]. In the short term of development, at stages 1 and 2 of the innovation cycle, this is ensured by directive management with a strong formalization of structures. However, at the same time, the innovative activity of the personnel and their susceptibility to high-tech environmental factors are low. This determined the development of factor parameters for the quality of additional KFUs and the expansion of the roles of personnel with self-organization capabilities.

Procedure 2.3 for the development of an additional KFU-3 for accelerating the impact on the quality parameters of the integration and combination functions in the complex and the enterprise should be aimed at creating speed controllers for the use of KFU-1 and -2 in the range ($x_{11} - x_{15}$) of the assessment of the KUS ($x_{i\text{cp}}$.).

Stage 3 of the analysis of the genesis of the theoretical and methodological foundations of similar studies (see Table 1) substantiated the choice of the equilibrium principle that determines the compromise between the goals of the long-term innovativeness of the development of the complex and individual enterprises of the complex in terms of environmental factors and types of sustainability. The theory of organizations made it possible to detail the relevant processes in the chain of stable states of the system (through imbalances), which are considered to be zones of crisis changes [8,16,17]. This determined the development of an understanding of the balanced scorecard chain for the convergence of resources in the system of processes, "the concept of improvement—foresight management and training—high-tech development". Such a system is distinguished by solving problems of imbalance of goals at two levels. Firstly, the quality of managing the coordination of individual and group interests of economy and innovation within an individual enterprise has been improved. Secondly, a similar result is achieved in the aggregate of enterprises and objects of the knowledge economy according to the recommendations of the Complex Center.

3.3. Models and Methods for Studying the Processes of Functioning of the Foresight-Controlling Mechanism

The properties of forecasting and monitoring environmental factors of the mechanism of foresight-controlling of enterprise development goals in innovation cycles ensure the stability of the compromise between the goals of economy and innovation as part of the complex [3–6,23,24]. The minimum reserves for improving the quality of control are determined by the methods of the theory of random transformations [17,26]. A number of studies have proposed to identify reserves using neoinstitutional methods [16,20,28]. Therefore, the development of quality indicators for the functions of formation and regulation of adaptive mechanisms [3–6,23,24] is based on theories of microeconomics. In particular, the theory of the ecology of populations of organizations has been developed in relation to improving the quality of regulation of the interaction of enterprises in the complex in procedure 1.2 of the theoretical model.

To ensure four types of economic sustainability, substantiated in the theoretical part of the study for individual stages of the innovation cycle, special mathematical approaches are needed to model the processes of the functioning of the mechanism. The mathematical foundations for evaluating and analyzing the effectiveness and speed of jump and step physical and economic processes justify the use of an approximating sequence of n nested functions. They have derivatives of any order and are estimated by the sequence of the resulting economic property H_n depending on additional control functions (n = 3). This

can be considered a digital simulator of the foresight-controlling mechanism in terms of the factorial parameters of the quality of their application x, developed in the theoretical part of the study (2):

$$H_n(x) = 0.5(1 + f_n(x)). \quad (2)$$

Estimation of the first derivative makes it possible to model changes in the rate of influence of the quality parameters of the foresight-controlling mechanism regulators on the indicator-property of the efficiency of the innovative development of an object (3):

$$\frac{dH_n(x)}{dx} = \frac{\pi^{n-1}}{2^n} \prod_{k=1}^{n-1} \cos\left(\frac{\pi}{2} f_k(x)\right) \cdot \cos x \quad (3)$$

The application of functions (1) and (2) models changes in efficiency and speed over the periods of cycles 1 and 2. The decrease in indicators according to the stability criteria of the functional (UUf) and structural (UUs) types in cycle 1 is justified. It begins the experimental application of new control functions in the mechanism by the personnel of the enterprise. The necessity of the maximum rate of increase in the indicator-property Hi at the stage of cycle 2 of the abrupt transition is determined by the maximum of the criterion of stability of the bifurcation type (Bb). This means an increase in the variability of the effects of the quality parameters of standard and additional control functions in the corresponding mechanism controller. In the zone of organizational methods and stabilization of the achieved level of efficiency of technologies (stage 4), the criterion of the economic–organizational type of sustainability (Ue) is maximized. To assess the frequency and directivity of the impacts of the parameters, the maximum adjusted value $x = 0$ of the function $H_i(x) = A_n$ is determined by substituting the values of the factor variable of the quality parameters into expression (4):

$$A_n = \frac{\pi^{n-1}}{2^n} \quad (4)$$

An analysis of the dynamics of the market situation in the regional agglomeration of the emerging complex revealed that with an evolutionary increase in the number of types of enterprises under conditions of constant innovation, their density in the agglomeration grows. Therefore, the duration of the life cycle of such enterprises tends to decrease. This substantiates the hypothesis of the expediency of including an enterprise in the complex according to the criteria for comparing upward (due to the growth of sustainable development) and downward (due to a decrease in the efficiency of development) trends. Estimates of the number of created $Nc(x_i)$ and decaying $Np(x_i)$ enterprises in the competitive sectors of the complex make it possible to determine four boundaries of the stability zone for periods of cycles 1 and 2 (Figure 1). Indeed, an increase in the CUE > 1 determines an increase in the number of enterprises, and a decrease in the long term leads to an increase in the number of their decays according to the criterion of quality parameters (5):

$$UUE = Nc(x_i)/Np(x_i) > 1 \quad (5)$$

The criterion ensures the preservation of the indicator-property $\overline{H}$ (according to Formula (1)) in the extended zone of stability of high-tech development at stage 4 of the cycle. It provides the conditions for a normalized compromise of the goals of efficiency and innovation of enterprises in the industry niche. The speed of their high-tech transformations in the zone is stable in assessing the criterion of the indicator of SD in cycle 2 in magnitude. To confirm the trend, mathematical models for the analysis of generalized and step functions were chosen. Their application to assess the evolutionary and stepwise (jump-like) processes of development of not only technologies, but also management methods, is substantiated and shown [5–8,23,24].

To reveal the content of this concept, the use of a theoretical model of resource integration methodologies [3] and the FCIR mechanism is justified. This determined the

development of a conceptual analog model for managing resource integration. It provides a meaningful description of the qualitative factors of transformation of the organizational and technological structures of the economy in the cycle of transformations of objects in terms of adding value in the formed scientific and educational complex (SEC). The model concretizes the characteristics of the necessary innovative transformations of the enterprise according to the factors of transition to the 5–6th OTMs and the conditions of industry 4.0. The stages of the cycle of spatio-temporal coordination of the integration and balancing effects of diversified resources (Figure 1) are characterized by the processes of improving the quality of management of innovative transformations of the facility based on the regulatory effects of the FCIR mechanism. The use of the criterion for ensuring economic sustainability can be assessed by a decrease in the entropy of synergy of the resulting indicators in the zone of convergence of the goals of innovation and the effectiveness of its development in a complex (given in the materials of another article). In the space and time of the dynamics of processes, four stages of the "high-tech" and "tech-hume" methods and the types of processes are distinguished.

The model justifies the implementation of the following processes: stagnant modernization or self-organizing, leading to, however, degradation, for example, to a decrease in the cost of an enterprise (quadrant 1); evolutionary, medium-tech and manageable, taking into account the relationship with the objects of the complex of a temporary, for example, design nature (quadrant 2); revolutionary intermittent ones based on high-tech technology and regulation functions taking into account constant, for example, cooperative interconnections of the studied objects of the complex (quadrant 3); stabilization with characteristics of evolutionary changes in functions based on the object control functions and regulation by the coordination structures of the complex based on tech-hume technologies (quadrant 4). It is proposed to include the processes of implementing the stages of the cycle 1–4 of long-term development in the foresight technology. The directionality and closedness of the arrows show that there can be several cycles, depending on the focus of the object's transformations on the 5th or 6th modes.

To implement the research concept, we have developed a conceptual model for representing evolutionary processes and revolutionary processes of system transformations. The analog-meaningful characteristics of the model in Figure 1 are implemented by four groups of methods and processes for integrating resources in a cycle. The impacts of the four types of microenvironment factors are qualitatively defined by the names of the corresponding resources indicated along the perimeter of the transformation cycle matrix. A digital model of short-term processes of jump-like transformations of a high-tech type is described by a set of so-called (in mathematical models of generalized functions) nested functions of their analytical approximation. At the same time, the number and direction of their action is interpreted by us by the corresponding number of special, additional functions for regulating the target indicators of the development of SEC facilities, performed in the newly formed Resource Integration Center (RIC). Interpretation of the jump-like nature of the actions of control functions can be based, as we proved [4–6,23,24], by using the approximation of the Dirac function of singular form proposed by S.V. Alyukov [8] (6):

$$\delta(x) = \begin{cases} +\infty, \, x = 0, \\ 0, \, \forall x \neq 0, \end{cases} \tag{6}$$

at that $\int_{-\infty}^{+\infty} \delta(x) \mathrm{d}x = 1$.

The value x in this case is taken as a generalizing indicator of the factor effects of innovative technologies "high-tech" and methods "high-hume" of the 5–6th OTMs of the economy. In this study, they model the accelerating and balancing effects of the additional functions of the RIC on the increase in time t of the level of innovation, as factor indicators of the use of new technologies and management methods. These functions-regulators of the control mechanism should affect the main resulting property of the development efficiency

(H) of the complex objects. However, the indicated ideal mathematical representation of influences does not allow for the revealing of the real practical content of cause-and-effect relationships. S.V. Alyukov established that the meaning of singular generalized functions is revealed in their approximations, perceived as the limits of some approximating sequences of ordinary functions (for example, step functions) [8]. The problem is that step functions have discontinuity points at which they are not mathematically differentiable. This does not allow one, in a digital analytical form, to represent the organizational behavior of a complex system of objects using the technologies "high-tech" and "tech-hume".

It has been proven that a deeper study of the possibilities of improving the quality of control and regulation is achieved by eliminating the paradox of space and time compression of jump-like processes for making the necessary decisions. The paradox is observed during the period that is theoretically instantaneous for technical systems (displayed by the Dirac function and approximated by S.V. Alyukov), and practically—a short (up to a year) duration of high-tech transformations. To analyze the transition processes, it is proposed to single out the stages of cycle 1 of the evolutionary formation of additional functions, FCIR, RIC and SEC mechanisms, as well as cycle 2 of abrupt processes of the emergence of new management structures. In a certain range of changes in factors, this makes it possible to quantify the parameters of both evolutionary processes and the abrupt transition of a singular type to high technology or a new educational and organizational method. It was found that such transitions are insufficiently effective in cycle 2 under postsingularity conditions when using only basic standard control functions. A complementary integration of the resources of SEC facilities in projects or plans for their long-term cooperation is required.

An increase in the space and time of integration of possible resources necessitates an analysis of the economic parameters of the singularity of the jump-transition to the 5–6th modes. Indeed, time and material resources are needed for changes (advanced training, goal setting, planning and implementation of management decisions, plans or projects). S.V. Alyukov proved that the most accurate description of the processes of development of objects of the virtual network of SEC is achieved when the nested functions are approximated by a growing number A in the range A = (9,10,11). Figure 2 shows the graphs of the corresponding successive approximations obtained by formulas (7). A planar representation of the effect of space–time expansion is given in cycle 1 of a jump-transition from a situation of imbalance of low-tech goals to cycle 2 of high-tech type processes. It is determined by a digital model (2) for assessing the development efficiency of SEC facilities.

$$H_9(x) = 0.5(1 + \sin(\mathrm{A}(\mathrm{A}(\mathrm{A}(\mathrm{A}(\mathrm{A}(\mathrm{A}(\mathrm{A}(x)))))))))$$

$$H_{10}(x) = 0.5(1 + \sin(\mathrm{A}(\mathrm{A}(\mathrm{A}(\mathrm{A}(\mathrm{A}(\mathrm{A}(\mathrm{A}(\mathrm{A}(x))))))))))) \quad (7)$$

$$H_{11}(x) = 0.5(1 + \sin(\mathrm{A}(\mathrm{A}(\mathrm{A}(\mathrm{A}(\mathrm{A}(\mathrm{A}(\mathrm{A}(\mathrm{A}(x)))))))))))$$

where $\mathrm{A}(x) = \frac{\pi}{2}\sin x$ is the amplitude of the approximating efficiency function.

The thickness of the lines in the figure increases with the increase in the number of nestings of approximating functions, interpreting the increase in the integration of resources and efficiency Hi in terms of innovation factors x. At A = 18, the approximation corresponds to the approximation of the Dirac function (vertical line in Figure 2).

The use of foresight technology with the use of a combination of analog and digital models for the organization of reducing the techno-humanitarian imbalance by using the technologies "high-tech" and "tech-hume" is substantiated. Mathematical mapping of processes based on a digital model (2) allows us to distribute, in time and space, stages 1–4 of the cycle of the conceptual analog model of innovative development and quantitative estimates of efficiency. The standard-traditional model of priorities and the sequence of methods "I–IV" of objects inclusion into the processes of coordinated development and integration of resources of fundamental and applied science, technology and production reflects the impact only of the factors of 3–4 modes. Currently, they can provide insufficient efficiency of low- and medium-tech transformations, since the factors are represented only

by the intellectual capabilities of scientific and educational complexes with low competencies of innovation [5,6]. Their potential corresponds to a predominantly industrial type of economic development (shown by a decrease in efficiency in cycle 1 in Figure 2 and corresponding to stage 1 of the theoretical model in Figure 1). The sequence of impacts of methods and resources of objects in the conditions of industrial and postindustrial economies can be shown by four levels of models of methods of space–time integration in SEC. Management of the organization of integration processes is proposed to be substantiated by two types of analog models: educational and scientific transfer (EST) technologies and methods; network organization of the impacts of industry 4.0 methods in foresight technology (NOIF).

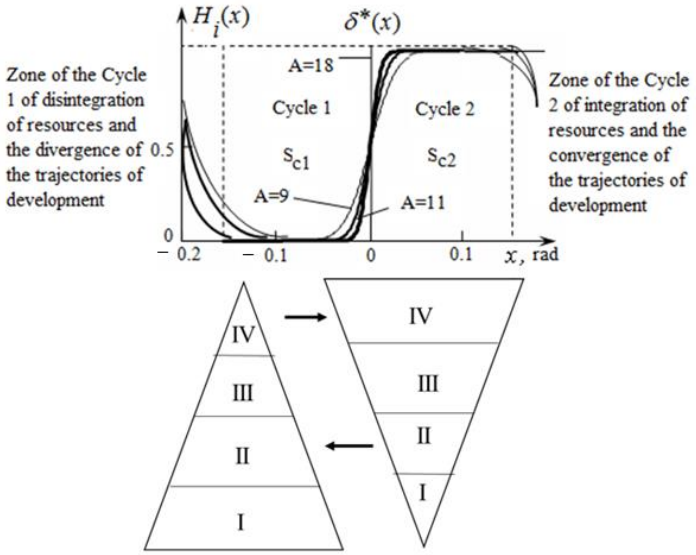

Figure 2. Modeling the processes of integrating resources of educational and industrial objects in the mechanism of combining digital and analog approaches to the sustainability of innovative transformations (Source: developed by the authors).

The content of level I of the EST model represents the methods of secondary and higher education as resources of the corresponding objects to provide initial knowledge of applicants and students of general theoretical unified types of activity. Level II is the objects and methods of higher education that transform the resources of initial knowledge into the assets of professional skills of the bachelor graduate. The most significant, at level III, are methods of acquiring the competencies of a designer and researcher of resources of innovative transformations by high-tech creative methods (ideally) in the form of a specialist or master's degree and postgraduate studies. The effectiveness of the transformations is determined by the purpose of level IV as methods of transferring innovative scientific achievements to the sphere of production and consumption based on the professional competencies of designers and researchers within the SEC.

The standard orientation of resource integration is realized by using the analog model of EST by the methods of the pyramid, or the "ladder of knowledge" in the sequence of methods "I–IV". The analysis of practice showed that the results of the implementation of the methods do not correspond to the qualitative indicators of the postindustrial economy of industry and scientific and educational complexes 4.0. The dynamics of a decrease in its efficiency $H(x)$ from a value of 0.5–0.6 of the maximum (shown in the digital model by the dashed line in cycle 1 in Figure 2) reflects the insufficient capabilities of the EST model. Indeed, the level of development of human capital, as the competence of innovative transformations, does not use the skills of multidisciplinary work in a virtual team. Meta competence of self-management by attention, flexibility of development potential, ability to constantly learn while not meeting the requirements of factors of the 5–6th modes of the

economy are important. It is necessary to apply industry 4.0 methods in the sequence of implementation of methods of the model of NOIF of the type of inverted pyramid "IV-I".

We propose to include a subsystem for increasing the controllability of the foresight technology into the structure of the FCIR mechanism. Additional engine control functions are designed to regulate resource integration. At the same time, methods of combining digital and analog approaches are used to qualitatively and quantitatively represent the cycle of processes of the evolutionary and abrupt development of an object. To combine analog and digital models, this study proposes the authors' concept of such technology. It is understood as a techno-visionary strategy of foresight in an analog–digital platform of continuous formation of a trend of evolutionary and abrupt processes of formation of characteristics of the future state of objects of a virtual complex. The strategy is being developed at the RIC on the basis of an integration-balancing combination of interdisciplinary models and methods of expert assessment, mathematical modeling and futurology based on a large database. The target indicators of the strategy are considered as factors-challenges of the postindustrial knowledge economy of the 5–6th modes, implying the use of "breakthrough" capabilities of the "high-tech" technology and methods according to the levels of the NOIF model. The following indicators can be applied: IV—an increase in the volume of large databases for digital modeling and the development of digital twins of equipment elements and objects based on artificial intelligence; III—scaling of the block-chain technology and other technical means of the "high-tech" type for the organization of multidisciplinary communications of objects and project groups in the expanded virtual space of the network formed by the SEC; II—an increase in the scale of materials design based on the principles of ultrahigh efficiency, minimum energy and material consumption of analogues of living beings and nature; I—an increase in the share of new materials based on the methods of quantum mechanics, 3D printing, augmented reality, the Internet of things, etc. [5,24].

Modeling the processes of integrating resources of educational and industrial objects in the mechanism of combining digital and analog approaches (Figure 2) to the sustainability of innovative transformations determines the use of a digital mechanism simulator with four types of regulators that affect the efficiency of innovative development of an enterprise according to the criteria of specialized types of sustainability. They correspond to the four stages of the conceptual analog model processes (Figure 1).

The functional-type regulator models change in the speed of processes at stage 1 of low-innovation modernization of enterprise technologies and the formation of the FCIR mechanism (quadrant 1 of the model in Figure 1). Modeling on the basis of the first derivative of the approximation of the efficiency function of the innovative development of the enterprise $H_9(x_i)$ shows the growth potential of effective sustainability. The simulation displays the procedure for applying the additional specific control function (KFU-1) proposed in the methodology [6]. It is necessary for the integration of resources and quality parameters of its coordination in the Center of the complex with standard enterprise management functions. KFU-1 is assessed by the impact of the KU*i* (chisr.) coefficient on the assessment and adjustment of planned and target indicators of innovative development strategies (projects). The result is determined by summing the average sums of estimates of the quality control parameters in the range (x_1–x_5) (8):

$$\text{KU}i\ (x_{i\text{cp}}.) = x_{1\text{cp}}. + x_{2\text{cp}}. + x_{3\text{cp}}. + x_{4\text{cp}}. + x_{5\text{cp}}./5 \quad (8)$$

At the same time, there is no estimated increase in the resulting property, shown by negative values of efficiency and innovation. This is due to the low intensity of regulatory impacts of KFU-1 at stage 1 for the integration of resources using the five relevant quality parameters of the foresight-controlling mechanism. In the Center of the complex, only an experimental coordination of the intensity of their application with four similar indicators of the quality of the standard functions of the enterprise (the total number of parameters in Formula (2) corresponds to the number of nested functions) takes place according to the criterion of maximizing the VUf.

The structural-type controller is used to simulate the processes of acceleration of functional type actions. The second derivative interprets the increase in the intensity of the use of standard functions in the new structure of the enterprise. The formation and the beginning of the application of additional CFU-2 combining the innovative capabilities of the objects of the complex is represented by a function of the effectiveness of its innovative development with increased interaction $H_{10}(x_i)$. The results of the regulatory actions of the mechanism are determined taking into account the coordination of five additional and five standard quality parameters according to the criterion of maximizing the SCL. Such methods, indicated in quadrant 2 of the analog model, provide technologies with a medium level of innovation. The procedure for using the additional KFU-2 is designed to combine resources, object structures and quality parameters for its coordination in combination with standard enterprise management functions. It is determined by the formation of the structural elements of the enterprise for organizing the effects of the coefficient KUK($x_{i\text{cp}}.$) of the function, determined by the averaged sum of the parameters of the quality of regulation in the range ($x_6 - x_{10}$) (9):

$$\text{KUK}\ (x_{i\text{cp}}.) = x_{6\text{cp}}. + x_{7\text{cp}}. + x_{8\text{cp}}. + x_{9\text{cp}}. + x_{10\text{cp}}./5 \quad (9)$$

The bifurcation-type controller models options for jump-like processes of increasing efficiency. This reflects the processes of the abrupt transition of high-tech transformations to the zone of positive efficiency. The maximum speed and degree of impact of the coefficients of integration and combination of additional KFU-1 and -2 are required for the development of high technologies and a new regulatory mechanism (quadrant 3) of innovative development. The results of speed control are shown by the function $H_{11}(x_i)$ depending on the effects of the additional KFU-3. It affects the predictability of CSF-1 and -2 growth rates when coordinating and using five additional and six standard quality parameters for the criterion of maximizing VLL. The procedure for applying the additional KFU-3 ensures the acceleration of the effects of the quality parameters of the KFU-1 and KFU-2 functions. It is aimed at the intensity of the use of speed controllers. As an expert assessment, a coefficient for improving the quality of speed control is proposed, determined by the effects of the averaged sum of parameters in the range (x_{11}–x_{15}) of the assessment of the coefficient Kus ($x_{i\text{cp}}.$) (10):

$$\text{KUs}\ (x_{i\text{cp}}.) = x_{11\text{cp}}. + x_{12\text{cp}}. + x_{13\text{cp}}. + x_{14\text{cp}}. + x_{15\text{cp}}./5 \quad (10)$$

The regulator of the economic–organizational type stabilizes the results of the functioning of the accelerators of the first three types and therefore is modeled by the system of Equations (1)–(5). Lines of increasing width and boldness show graphs of the functions $H_9(x)$, H_{10} (x) and $H_{11}(x)$, displaying seven trajectories of the enterprise development. They are provided by the application of technologies and management methods of the increasing innovativeness of the seven high-production technologies. The coordination of the functions of managing the integration, combination of resources and the speed of their impacts when using the regulators of the foresight-controlling mechanism contributes to the stabilization of efficiency. Equations (1)–(5) are used to model the velocities of additional KFU-1–KFU-3 by estimating the first derivatives of the approximations of the functions $\frac{H_9(x)}{\mathrm{d}x}$, $\frac{H_{10}(x)}{\mathrm{d}x}$ and $\frac{H_{11}(x)}{\mathrm{d}x}$. Therefore, it is necessary to adjust the regulators of the mechanism by predominantly nonadministrative organizational methods according to the criterion of maximizing the CUE.

4. Results of Organizational Design of the Processes of Functioning of the Mechanism of Foresight-Controlling of Enterprise

Organizational design was carried out in accordance with the principles of centralization and decentralization of powers. In the theoretical part of the study, it is substantiated that a single FCIR mechanism for enterprises in a complex or a regional cluster provides new opportunities for combining mechanistic and organic models of organizational design. Procedures and operations for designing managerial decision-making to improve the struc-

ture, coordination and control of the processes of interaction between the enterprise and the objects of the complex are carried out according to the stages of the analog model of the innovation cycle of the development of the object of study in the procedures for the formation and functioning of a new mechanism. Such procedures and operations for the implementation of solutions have been tested in the formed analog–digital platform of the Center of the complex (cluster).

The enterprise—the object of research and organizational design at the initial stage of transformations at the initial stage of its decomposition—was in the conditions of the 3–4th modes of the industrial-type economy [2–6]. It had an average headcount of 1500 people and belongs to the engineering industry. The production of products with high added value but lack of innovation exacerbated the problems of competitiveness and declining demand. This determined the need for high-tech transformations according to the factors of the 5–6th modes.

The multiparametric approach to determining the output (resulting) variable of the efficiency of the innovative development of an enterprise has determined its vector representation in the theoretical and methodological part of the article. Numerical characteristics $H_n(x_i)$ are defined at $n = 3$. Arguments (factorial indicators) of three additional KFUs substantiated the coefficients for estimating the quality parameters of regulation of the impact of input variables, or parameters $\boldsymbol{x_i}$ (where $i = 1, \ldots, n = 15$ is the number of regulation parameters). The coefficients were established by ranges based on the generally accepted L. Harrington scale [36]. Experts assessed the quality of regulation in terms of the degree of actual and planned impacts of each parameter based on arithmetic mean estimates of $x_{i\text{cp}}$. by 15 specialists of the new structure of the Center of the complex. Five intervals of fractions of a single segment were used, characterizing very high (1–0.8), high (0.8–0.63), medium (0.63–0.37), low (0.37–0.2) and very low (0.2–0) degree of impact of the parameters in the specified verbal–numerical scale. The values of coefficients KUj ($x_{i\text{cp}}$.), where $j = 3$, are determined.

The representativeness of a relatively small sample of data is ensured by a survey of experts from the group of developers of the scientific design study belonging to the subgroups of researchers, designers, technologists, etc. Randomization of subgroups was used when these experts could get into them randomly in the study of the characteristics of the quality of control of objects belonging to different categories. A sample of a nonprobabilistic type is acceptable for approximate modeling of processes that is acceptable for the purposes of organizational design of the foresight-controlling mechanism. Therefore, the sampling error was not determined from the simulation results.

The averaged actual estimates of the coefficients are determined according to the Equations (1)–(5). In each subsequent innovation cycle, they were summed up with their values achieved in the previous cycle of improving the quality of regulation of the efficiency of the innovative development of an enterprise in order to stabilize the achieved level. The coefficients given in Table 3 determine the necessary degree of subsequent adjustment of the planned and target quality indicators of KFU-1—KFU-3 of an enterprise to increase the innovativeness of its innovative development strategies in a complex (cluster) according to knowledge economy factors.

The objectivity of the estimates was tested on the basis of initial training recommendations to experts using pattern recognition methods in fuzzy sets and verified by numerical methods [11,31,34]. The initial parameters in cycle 1 or their subsequent adjustments were carried out according to the criterion of economic sustainability. For approbation, the parameters of each additional control function that most affect the quality of regulation were used (the full parameters are given in the theoretical and methodological part of the study). The impact of the additional CFU-1 was assessed by the following coefficients-regulators: the degree of manifestation of the innovative competencies of researchers (project developers) of the complex objects (x1av.) and the flexibility of their structures (x2av.). To regulate KFU-2, the following parameters were taken into account: the degree of awareness of researchers and developers about the possibilities of high-tech development of the enter-

prise (x6av.) and the efficiency of establishing relationships in the space of the complex, taking into account environmental factors (x7av.). The application of KFU-3 was evaluated according to other parameters: the degree of interest of enterprise managers in accelerating innovation (x11avg.), the promptness of assessing the situation, taking into account environmental factors (x12avg.), and the speed of perception by the company's personnel of the vision and prospects for high-tech development (x13avg.). The new mechanism stabilizes the zone (see Figure 1) of a compromise between the goals of ensuring innovation and reducing economic losses according to the criterion of economic and organizational type of sustainability (Ue). This is provided by the regulators of the mechanism, which increase the reliability of predicting the normalized organizational–behavioral and economic indicators of the quality of the impact of the three management functions and their standard types on the economic development of the enterprise (Table 4).

Table 3. Average actual coefficients of quality of regulation of efficiency by stages of the enterprise development cycle, shares of a unit.

Cycle Stages	Characteristics of the Cycle Stages of the Development Strategy Selection Matrix Model	Average Expert Estimates of the Impact of Speed Parameters on Other Functions	Average Expert Estimates of Control Quality Parameters' Integration of the Resources of the Facilities of the Complex	Average Expert Estimates of Quality Parameters for Managing the Combination of Resources of Complex Objects
1	Minimum quality of technology upgrades	Cycle 1: Kus ($x_{i\text{cp}}$.)) = 0.10 Cycle 2: KUs ($x_{i\text{cp}}$.) =0.10 + 0.29 = 0.39	Cycle 1: KU*i* ($x_{i\text{cp}}$.) = 0.10 Cycle 2: KU*i* ($x_{i\text{cp}}$..) = 0.39	Cycle 1: KUK ($x_{i\text{cp}}$.) = 0.10 Cycle 2: KUK ($x_{i\text{cp}}$.) = 0.39
2	Low- and medium-quality regulation of economic development	Cycle 1: Kus ($x_{i\text{cp}}$.)) = 0.29 and 0.5 Cycle 2: KUs ($x_{i\text{cp}}$.) = 0.29 + 0.29 = 0.58 and 0.79	Cycle 1: Kus ($x_{i\text{cp}}$.) = 0.29 and 0.5 Cycle 2: KUs ($x_{i\text{cp}}$.) = 0.29 + 0.29 = 0.58 and 0.79	Cycle 1: Kus ($x_{i\text{cp}}$.) = 0.29 and 0.5 Cycle 2: KUs ($x_{i\text{cp}}$.) = 0.29 + 0.29 = 0.58 and 0.79
3	High-quality regulation of high-tech development	Cycle 1: Kus ($x_{i\text{cp}}$.)) = 0.72 Cycle 2: KUS ($x_{i\text{cp}}$.)) = 0.72 + 0.10 = 0.82	Cycle 1: Kus ($x_{i\text{cp}}$.)) = 0.72 Cycle 2: KUs ($x_{i\text{cp}}$.) = 0.72 + 0.10 = 0.82	Cycle 1: Kus ($x_{i\text{cp}}$.) = 0.72 Cycle 2: KUS ($x_{i\text{cp}}$.) = 0.72 + 0.10 = 0.82
4	Stabilization of the quality of development results	Cycle 1: Kus ($x_{i\text{cp}}$.) = 0.29 Cycle 2: Kus ($x_{i\text{cp}}$.) = 0.29	Cycle 1: Kus ($x_{i\text{cp}}$.) = 0.29 Cycle 2: Kus ($x_{i\text{cp}}$.) = 0.29	Cycle 1: Kus ($x_{i\text{cp}}$.) = 0.29 Cycle 2: Kus ($x_{i\text{cp}}$.) = 0.29

Source: developed by the authors.

Table 4. Recommendations for assessing the normalized indicators of the quality of enterprise management by the factors of the knowledge economy, share of a unit.

Forecasts of Coefficients for Adjusting Indicators at Stages 1–4 of the Innovation Cycle	Normalized Organizational and Behavioral Indicators of Management Quality in the Knowledge Economy	Normalized Economic Indicators of Management Quality in the Knowledge Economy
1. Integration of resources based on KFU-1—the degree of manifestation of innovative competencies of researchers, developers of enterprises and facilities of the complex ($x_{1\text{cp}}$.) and the flexibility of their structures ($x_{2\text{cp}}$.): 1—KU*i* ($x_{i\text{cp}}$.) = 0.10 2—0.29 (low innovative development); 0.5 (medium innovative) 3—Ki ($x_{i\text{cp}}$.) = 0.72 4—0.29	1.1. The number of specialists (QC) who have shown innovative competencies in the structures of the enterprise in terms of the quality parameter x1av. for cycle period 1: Stage 1—0.10 QC 1.2. The number of specialists in project-type structures (groups, teams) according to the quality parameter x2av. for cycle period 1: Stage 2—0.29 QC or 0.5 QC Stage 3—0.72 QC Stage 4—0.29 QC	1.1. Investments (IP) in the creation of the structure of the Center and projects for the formation of the complex for the period of cycle 1: Stage 1—0.10 IP Stage 2—0.29 IP or 0.5 IP Stage 3—0.72 IP Stage 4—0.29 IP 1.2. Costs (FC) for improving the competencies of specialists for the period of cycle 1: Stage 1—0.10 FC Stage 2—0.29 FC or 0.5 FC Stage 3—0.72 FC Stage 4—0.29 FC

Table 4. *Cont.*

Forecasts of Coefficients for Adjusting Indicators at Stages 1–4 of the Innovation Cycle	Normalized Organizational and Behavioral Indicators of Management Quality in the Knowledge Economy	Normalized Economic Indicators of Management Quality in the Knowledge Economy
2. Combining resources based on KFU-2—the degree of awareness of researchers and project developers about the possibilities of high-tech development of enterprises (x_{6cp}.) and the interconnectedness of enterprises and facilities of the complex, taking into account environmental factors (x_{7cp}.): 1—KUK (x_{icp}.) = 0.10 2—0.29 (low innovative development); 0.5 (medium innovative) 3—KUK (x_{icp}.) = 0.72 4—0.72	2.1. The number of informed specialists (CI) about the possibilities of high-tech development of the enterprise in terms of the quality parameter x6av. for cycle period 1: Stage 1—0.10 CI 2.2. The number of interconnected enterprises (KV) and objects of the complex (quality parameter), which appeared during the period of cycle 1: Stage 2—0.29 KV or 0.5 KV Stage 3—0.72 KV Stage 4—0.29 KV	2.1. Costs (ZI) for raising the awareness of specialists for the period of cycle 1, including the use of information technology: Stage 1—0.10 ZI Stage 2—0.29 ZI or 0.5 ZI Stage 3—0.72 ZI Stage 4—0.29 ZI 2.2. Investments in the development of projects (IP) of high-tech development of the enterprise for the period of cycle 1: Stage 1—0.10 IP Stage 2—0.29 IP or 0.5 IP Stage 3—0.72 IP Stage 4—0.29 IP
3. The speed of application of the functions of integration and combination based on KFU-3—the degree of interest of business leaders in accelerating innovation (x_{11cp}.), the efficiency of assessing the situation taking into account environmental factors (x_{12cp}.) and the speed of perception by the personnel of enterprises of the vision and prospects for high-tech development (x_{13cp}.): 1—KUs (x_{icp}.) = 0.10 2—0.29 (low innovative development) 0.5 (medium innovative) 3—KUs (x_{icp}.) = 0.72 4—0.29	3.1. The number of managers (CR) interested in the acceleration of innovation processes in the period of cycle 1 in terms of the quality parameter x_{11cp}.: Stage 1—0.10 CR 3.2. The number of environmental factors (CF) taken into account in a timely manner (quality parameter x12av.), which ensured an increase in the speed of perception of the vision by the personnel of the enterprise over the period of cycle 1 (quality parameter x_{13cp}.): Stage 2—0.29 CF or 0.5 CF Stage 3—0.72 CF Stage 4—0.29 CF	3.1. Investments in the development of a foresight mechanism (IFM) to increase the efficiency of the innovative development of an enterprise for the period of cycle 1: Stage 1—0.10 IFM Stage 2—0.29 IFM or 0.5 IFM Stage 3—0.72 IFM Stage 4—0.29 IFM 3.2. Economic effect (EE) from the implemented short- and medium-term projects of innovative development for the period of cycle 1: Stage 1—0.10 EE Stage 2—0.29 EE or 0.5 EE Stage 3—0.72 EE Stage 4—0.29 EE

Source: developed by the authors.

The predicted level of economic and organizational sustainability of the development of enterprises (Ue) was used as a criterion that determines the stability of the indicator-property of efficiency in the range of compromise of long-term development interests at stage 4. It was estimated by the ratio of the indicators of the number of created Nc(x_i) and decaying Np(x_i) enterprises in competitive agglomeration industries of the complex objects according to the stability criterion (5) CUE > 1.

Information on the number of established and liquidated enterprises was taken from official data on their state registration and bankruptcy. If the criterion according to Formula (6) was not observed at certain stages of the cycle, a conclusion was made about an imbalance in the goals of efficiency and innovation. The effectiveness of the transition of the enterprise to high technologies was facilitated by the use of a new mechanism for regulating and adjusting indicators implemented on the basis of the feedback of the model in Figure 2. For example, according to the specified criterion, decisions were made to intensify the impact of the regulators of the mechanism that determine the increase in the quality parameters of additional KFU-1–KFU-3 for the value of VUE < 1 (6). This formed the recommendations of the Center of the complex on adjusting the planned and target economic indicators, supplementing Table 2, and aimed at increasing: the novelty of the technologies used; the share of costs for improving the competencies of personnel associated with the development and use of information and communication technologies; investments in new technologies; development of software tools to enhance interaction with suppliers and consumers of goods and services.

The proposed methodological approach to combining the capabilities of analog models of EST and NOIF with a digital mathematical model allows us to draw some conclusions.

A method for the development of a prototype, or "twin", of the system for managing the strategic processes of high-tech transformations of objects according to the factors of the economy of the 5–6th modes is proposed. It allows you to evaluate and regulate the indicators of efficiency and innovativeness of the implementation of processes in repeating cycles 1 and 2. An analog–digital model of the resource integration management mechanism (RIMM) has been formed to organize the coordinated and continuous application of educational methods, science, design and other necessary resources by challenge factors of high-tech production. The use of special additional management functions and target indicators of efficiency and innovativeness of the impacts of the development strategy of the complex objects in the RIC is shown in Figure 2 by arrows. It interprets the forward and backward linkages of the mechanism for long-term planning or the development and implementation of a series of projects in cycles of innovative foresight transformations. The mechanism also makes it possible to regulate the rate of change of priorities and direction of methods for organizing the transition to the 5–6th modes of the postindustrial economy in cycle 2. The possibilities of such processes are the result of additional research and are reflected in another article.

5. Conclusions

5.1. Conclusions from the Results of the Study

The results of the study reveal the theoretical and methodological foundations for improving the quality of managing the interaction of enterprises in a complex or regional cluster of knowledge economy objects. The proposed methods for managing the integration of functionalities and the combination of controlling and foresight management subsystems help to accelerate decision-making on the coordination of interests in the regional agglomeration system. The development of additional management functions and quality parameters of efficiency regulation complements the tools for increasing the sustainability of the balanced innovative development of enterprises in the complex. The introduction into scientific practice of reasonable assessments of quality parameters, monitoring of integrated factors of the external and internal environment and a single mechanism for foresight-controlling (FCIR) helps to increase the reliability of forecasts of normative and target indicators in the zone of stability of the compromise between indicators of efficiency and innovativeness of enterprise development. The processes of functioning of the mechanisms of enterprises are adjusted in the digital platform of the Center for Coordination of the Goals of Enterprises and the complex in the system of balanced indicators of the quality of regulation. An effective organization of interaction was developed and tested in the design part of the study. A number of practical results have been obtained to improve the quality of assessment and regulation of coordinated impacts when integrating foresight and controlling functionality in a single mechanism. This was achieved by using additional control functions and quality parameters for their regulation in the new mechanism. The forward and backward links allowed one to apply the models of theory and procedures of methodology by methods of integration of functionals and combinations of resources of the knowledge economy in operations for the development and implementation of methods. Evaluation and regulation of the intensity and speed of development of the enterprise on the factors of transformation of the ways of the economy in the complex is quantitatively substantiated by the methods of mathematical modeling of the effects of additional management functions on the indicators of the quality of regulation of efficiency. The quality parameters were changed at the stages of the enterprise's innovation cycle based on the results of assessments of the use of a digital simulator of four types of regulators using new sustainability criteria. The simulator of the FCIR mechanism is included in the digital platform of the new structure of the Center for the Coordination of Interests of the complex. Taking into account the expanded composition of the VUCA factors of the external and internal environment made it possible to increase the reliability of the forecasts for the adjustment coefficients for the planned and target indicators of the quality of regulation of the efficiency and sustainability of development.

The development of management theory methods makes a certain contribution to the science of managing the sustainable development of enterprises. We have proposed a new mechanism for foresight-controlling goals and strategies for managing their high-tech development. The mechanism is based on the author's methodology of integration-balancing management of the long-term development of an enterprise in a complex of objects of the knowledge economy in an environment of uncertainty according to sustainability criteria, specialized in the stages of an enterprise's innovation cycle.

5.2. Recommendations for the Application of the Results and Further Research Directions

The results of organizational design based on a multiparameter approach to assessing the quality of the functioning of the new mechanism made it possible to develop recommendations on the choice of strategies, indicators of plans and projects for the development of the enterprise-object of research. They are substantiated by a multiparameter approach to assessing the quality of the functioning of a new mechanism in the enterprise management system. The predictive indicators of increasing the speed of development of managerial decisions and the stability of forecasts of the efficiency of the processes of evolutionary and high-tech development have been identified. Additional specific management functions and quality parameters of their application are proposed to be used in plans and projects for the innovative development of an enterprise in accordance with the stages of its development cycle. This will contribute to a better organization of the transfer of accumulated experience and competencies of high-tech development in order to coordinate the interests of the enterprise in the complex. The implementation of the project in the engineering industry showed an improvement in the characteristics of organizational behavior and the efficiency of innovative development. Planned and forecasting levers have been strengthened to provide consumers with guaranteed properties of product quality and predict the conditions for its supply in high-tech strategies based on factors of the 5th–6th modes of the knowledge economy.

We used the research methods to create innovative transformations in the socio-economic and technical system of a large university and a number of industrial facilities with diversified resources. Continuation of research is expected in the areas of improving the systems of postindustrial agglomeration of the regions of developing countries using the mechanisms of FCIR objects in complexes of organizational and energy-technological purposes. Monitoring of environmental factors can be aimed at combining low-carbon and green energy resources, which contributes to the transformation of waste landfills as part of the complex into energy sources and carbon dioxide absorption zones.

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