Approach to Conceptual Modeling National Scientific and Technological Potential

Alexey B. Petrovsky[1,2,3,4](✉) and Gennadiy I. Shepelev[1]

[1] Federal Research Center "Informatics and Control", Russian Academy of Sciences, Prospect 60 Letiya Octyabrya, 9, Moscow 117312, Russia
pab@isa.ru

[2] Belgorod State National Research University, Belgorod, Russia

[3] V.G. Shukhov Belgorod State Technological University, Belgorod, Russia

[4] Volgograd State Technical University, Volgograd, Russia

Abstract. The paper presents a conceptual multilevel model of national scientific and technological potential in order to form and select options for the strategy of innovative development of the country. The model is based on the methodology of group verbal decision analysis and multidimensional assessment of innovations. The elements of the information-logical model and the intensity of connections between elements of different levels are evaluated by experts on qualitative criteria with verbal scales.

Keywords: Scientific and technological potential · Information-logical model · Group verbal decision analysis · Qualitative criteria

1 Introduction

The elaboration and justification of recommendations on the creation of promising high technologies that ensure innovative development of the country's economy are closely related to the forecast of the development of scientific and technological potential, assessment of the basic and applied significance of research results. Building methodological tools for multidimensional analysis of the state and trends of development of the national innovation system and the scientific and technological potential remains an important and still unsolved scientific problem [7, 8].

The paper describes a conceptual multilevel information-logical model of the national scientific and technological potential, which is based on the methodology of verbal decision analysis and a multidimensional assessment of innovation. The model allows creating and analyzing options of strategy for innovative development of the country. Qualitative criteria with verbal scales for expert evaluation of the model elements and connections between its elements are proposed.

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2 Conceptual Model of Scientific and Technological Potential

The important role of scientific advances and technologies in the modern and future world dictates the need for a reasonable choice of priorities. Priorities should ensure the maximum contribution of science and technology to the achievement of national goals. This implies a balanced strategy, optimal allocation of resources, and concentration of main efforts in actual research areas [1, 5, 12]. Priorities should be harmonized with the competitive advantages of the country and global trends in the socio-economic development. The complexity of solving this problem is exacerbated by the constant increasing the number of promising and breakthrough scientific fields and the potential points of growth generated by them, which leads to an expansion of the list of possible options for scientific and technological development.

Among existing approaches to assessing the level of innovation development, the most developed are the evaluation of technological competitiveness, proposed in [13], and the integral estimation of the national innovation system used by Eurostat [15], in which the innovation system is considered as a black box. The system output is the competitiveness of products and services, characterized by indicators of the technological state of production and the country export capacity for high-tech products and services. At the level of macroeconomic analysis, the system inputs are specially designed synthetic characteristics and the corresponding indicators. Input indicators are based on quantitative factors and expert estimates, which are converted into averaged scores, that is, the so-called quantitative approach is used. At the same time, quantitative models are too simplified for the analysis of the state and trends in the development of the country's scientific and technological potential [4, 16].

Multidimensional assessment of the means of achieving the goals of national innovation policy, directions and results of scientific research, high-tech technologies and areas of their practical application are related to the so-called poorly formalized and ill-structured decision problems, where there are both quantitative and, mainly, qualitative indicators with verbal grading scales. Methods of verbal decision analysis are most suitable for solving such problems [6, 10].

The proposed approach to structuring the subject area, developing a conceptual model and criteria for evaluating the national scientific and technological potential is based on a system analysis of the modern innovation system of Russia. The method of Multilevel Information-Logical Structures (MILS) is focused on expert evaluation and analysis of options for strategic decisions [6, 8]. The main ideas of the MILS method are as following.

1. Construct a conceptual model of the subject area as a multilevel information-logical structure.
2. Form lists of elements of each level of the hierarchy.
3. Develop indicators and criteria for evaluating elements at all levels of the hierarchy and the intensity of connections between elements of different levels.
4. Collect factual data and expert assessments of each element at all levels of the hierarchy.
5. Collect expert assessments of elements' connections at different levels of the hierarchy.

6. Build decision rules of selection at each level of the hierarchy.
7. Select the best or acceptable solutions, taking into account the decision rules and requirements for the intensity of connections between elements of different levels.

The conceptual multilevel information-logical model of the scientific and technological potential, designed to form and select alternative options for strategic decisions on the innovative development of the country, includes the following blocks (Fig. 1):

– goals of scientific and technological development;
– innovations in sectors of the economy;
– critical technologies;
– scientific and technical directions;
– resources ensuring the achievement of innovation development goals;
– mechanisms contributing to the achievement of innovation policy goals.

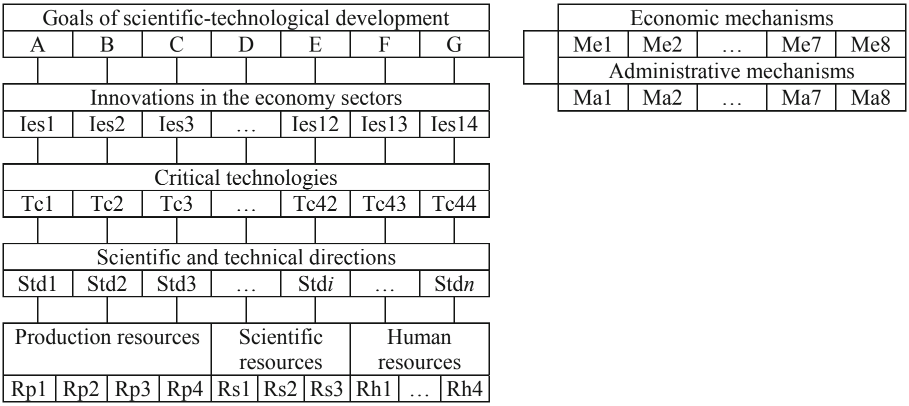

Fig. 1. Information-logical model of scientific and technological potential.

The purpose of the scientific and technological development of the Russian Federation is to ensure the independence and competitiveness of the country through the creation of an effective system for building up and the most complete utilization of the national intellectual potential [9]. The goals of the national innovation policy are the approved priority directions of scientific and technological development:

A. Transition to advanced digital, intellectual production technologies, robotic systems, new materials and methods of design, creation of systems for processing large volumes of data, machine learning, and artificial intelligence.
B. Transition to environmentally friendly and resource-saving energy, increasing the efficiency of extraction and deep processing of hydrocarbon raw materials, the formation of new sources, methods of energy transportation and storage.
C. Transition to personalized medicine, high-tech health care and health-saving technologies, including through the rational use of drugs (primarily, antibacterial).

D. Transition to a highly productive and environmentally friendly agricultural and aquatic economy, development and implementation of systems for the rational use of chemical and biological protection of agricultural plants and animals, storage and efficient processing of agricultural products, the creation of safe and high-quality, including functional, food products.
E. Counteraction to technological, biogenic, socio-cultural threats, terrorism and ideological extremism, as well as cyber threats and other sources of danger to society, economy and the state.
F. Connectivity of the territory of the Russian Federation through the creation of intelligent transport and telecommunication systems, as well as the occupation and retention of leadership positions in the creation of international transport and logistics systems, the development and use of space and airspace, the oceans, the Arctic and Antarctic.
G. Possibility of an effective response of Russian society to major challenges, taking into account the interaction of man and nature, man and technology, social institutions at the present stage of global development, including applying methods of the humanitarian and social sciences.

Innovations represent possible ways to achieve the goals of innovation development and are distributed across sectors of the economy. The list of innovations is formed by experts.

An innovation is defined by the Organization for Economic Cooperation and Development (OECD) as the application of new significantly improved products (goods and services), processes, new market methods or new organizational methods in business practice, in organizing workplaces or in establishing external relations [2]. According to Russian GOST, an innovation is "the final result of innovation activity that has been realized in the form of a new or improved product sold on the market, or a new or improved technological process used in practical activities" [3]. It is customary to distinguish the following types of innovation:

by a focus of action - basis innovations that implement major discoveries and inventions; improving innovations that implement small and medium-sized inventions; rationalizing innovations aimed at partial improvement of outdated generations of equipment and technology;
by a type of parameters - product innovations; process (technological) innovations; organizational and managerial (non-technological) innovations;
by a scale of distribution - the whole world; a country; an industry; a company.

The socio-economic and production-technological platform, where high-tech innovations are practically used, is the interbranch and industry-specific complexes: 1. Mining industry; 2. Energy; 3. Metallurgy; 4. Mechanical engineering and instrument making; 5. Defense industry; 6. Chemistry, forestry and biotechnology; 7.Agro-industrial complex; 8. Light industry; 9. Construction, transport, communications, information and communication technologies; 10. Environmental protection; 11. Health and welfare; 12. Education, science, culture, sports; 13. Trade and services; 14. Housing and household.

In order to become a successful innovation, a good idea must go through several stages of the "life cycle": the idea emergence - the possibility of using a scientific achievement for commercial purposes; the idea evolution - the development of a technology for the production of a new product that can be commercially implemented; the sample demonstration – the creation and presentation of a prototype to potential investors and customers; the product promotion - the creation of a demand in the market for new products; the consolidation in the market - the acquisition of confidence that a new product or technology will have a long and successful future in the existing market.

Critical technologies are the technologies that are important for the socio-economic sphere, national defense and state security. The list of critical technologies is approved by decree of the President of the Russian Federation and is periodically reviewed. Currently, the list includes 44 critical technologies.

Scientific and technical directions create the foundation for the development of critical technologies and include research in the field of understanding the processes occurring in society and nature, the development of nature-like technologies, human-machine systems, climate and ecosystem control; research related to the ethical aspects of technological development, changes in social, political and economic relations; basic research caused by the internal logic of the development of science, ensuring the country's readiness for great challenges that have not yet manifested and not received wide public recognition, the possibility of timely assessment of risks arising from scientific and technological development. The list of directions is formed by experts.

Resources ensuring the achievement of innovation development goals are divided into production, scientific and human resources.

Production resources include:

Rp1. Production facilities for the production of high technology products.
Rp2. Production capacity for the production of components and component base.
Rp3. Modern technological equipment, accessories, devices, tools.
Rp4. Functioning market of services for technological support of manufacturers.

Scientific resources include:

Rs1. Results of revolutionary scientific research that can dramatically affect the development of science and technology.
Rs2. Results of promising basic and applied research that can be quickly used in high-tech areas.
Rs3. Scientific and technical results of the possible borrowing of new knowledge and the reproduction of advanced promising technologies.

Human resources have components:

Rh1. Scientists and highly qualified specialists.
Rh2. Engineering and technical workers.
Rh3. Workers, employees and support workers.
Rh4. Administrative and management personnel.

Mechanisms contributing to the achievement of innovation policy goals are located at the level of objectives and are divided into economic and administrative.

Economic mechanisms are aimed at creating and mastering innovations, stimulating the production of high-tech products. These mechanisms include:

Me1. Demand for high-tech and high-tech products.
Me2. Demand for promising scientific and technical results.
Me3. Innovative activity of enterprises in the real sector of economy.
Me4. Innovative activity of small enterprises.
Me5. Function of the capital market.
Me6. Domestic investment in high-tech manufacturing.
Me7. External investments in high-tech production.
Me8. Transfer of knowledge and high technology to the domestic and global markets.

Administrative mechanisms are aimed at creating conditions that ensure the implementation of innovation, the economy's susceptibility to innovation. These mechanisms include:

Ma1. National strategy of innovation and scientific and technological development.
Ma2. Legislative and regulatory framework for the regulation of innovation.
Ma3. Public-private partnership in the implementation of innovations.
Ma4. Direct government support for small innovative enterprises.
Ma5. Support for basic and applied research, experimental development by large public and private corporations.
Ma6. Sectoral and regional venture funds, innovation financing agencies with the state participation.
Ma7. Support science cities, technopolises, science and technology parks.
Ma8. Information support of innovation activity.

3 Assessment and Analysis of Innovation Development Strategies

Elements of the information-logical model of the scientific and technological potential and connections between the elements are evaluated by several independent experts on many criteria and indicators, which have scales with detailed verbal formulations of quality gradations.

The innovation is characterized by the following indicators:

I1. Focus of innovation (basis; improving; rationalizing).
I2. Type of innovation (product; process; organizational and managerial).
I3. Scale of innovation (global; national; sectoral; intra-company).
I4. Significance of innovation for the development of the Russian economy (high; medium; low; difficult to estimate).
I5. Competitiveness of innovation (high; medium; low; difficult to estimate).
I6. Stage of development of innovation (idea emergence; idea evolution; sample demonstration; product promotion; consolidation in the market).
I7. Feasibility of innovation (less than 3 years; 3–7 years; more than 7 years; difficult to estimate).

The technology assessment criteria are:

T1. Focus of technology (basis innovation; improving innovation; rationalizing innovation).
T2. Importance of technology for the innovation creation (high; medium; low; difficult to estimate).
T3. Stage of technology development (fully developed; prototype developed; technical documentation developed; initial stage of development).
T4. Feasibility of the technology (less than 3 years; 3–7 years; more than 7 years; difficult to estimate).

The scientific and technical direction is estimated by the following criteria:

D1. Impact of the results obtained in the direction on the creation of critical technology (strong; moderate; weak; difficult to estimate).
D2. Change of the direction impact on the creation of critical technology in the future (will increase; will not change; will decrease; difficult to estimate).

The production, scientific or human resource is estimated by the following criteria:

R1. Resource accordance with the needs of the innovative development of the economy (fully; partially; not relevant)
R2. Resource availability (fully available; partially available; initial stage of formation; absent).
R3. Resource change in perspective (will increase; will not change; will decrease; difficult to estimate).
R4. Resource impact on the innovative development of the economy (strong; moderate; weak; difficult to estimate).
R5. Change of the resource impact on the innovative development of the economy in the future (will increase; will not change; will decrease; difficult to estimate).

The economic or administrative mechanism is evaluated by the following criteria:

M1. Mechanism accordance with the goals f the innovation policy (fully; partially; not relevant).
M2. Mechanism availability (fully available; partially available; initial stage of formation; absent).
M3. Mechanism change in perspective (will increase; will not change; will decrease; difficult to estimate).
M4. Mechanism impact on the achievement of innovation policy goals (strong; moderate; weak; difficult to estimate).
M5. Change of the mechanism impact on the achievement of innovation policy goals in the future (will increase; will not change; will decrease; difficult to estimate).

Mutual connections between elements of the information-logical model at different levels of the hierarchy are evaluated by the following criteria:

C1. Intensity of the elements' connection (high; moderate; low; absent).
C2. Change in the intensity of the elements' connection during the short term less than 3 years (will increase; will not change; will decrease; difficult to estimate).
C3. Change in the intensity of the elements' connection during the medium term from 3 to 7 years (will increase; will not change; will decrease; difficult to estimate).
C4. Change in the intensity of the elements' connection during the long term over 7 years (will increase; will not change; will decrease; difficult to estimate).

The peculiarity of group expertise procedures is the presence of many judgments that do not coincide with each other. The inconsistency of individual opinions is due to the ambiguity of the understanding of the problem being solved by different people, the difference in assessments of the same objects made by different persons, the specificity of the knowledge of the experts themselves, and many other circumstances. The combination of such assessments may have a complex structure in the attribute space, which is rather difficult to analyze in this space. It is not easy to introduce a metric for the objects' comparison. These difficulties can be overcome if we use another way of representing multi-attribute objects based on the formalism of the multiset theory [10, 11]. Multisets allow us to take into account simultaneously various combinations of the values of qualitative attributes, as well as their polysemy.

A multidimensional analysis of the research results' impact on the creation of promising high technologies, the choice of the best or acceptable strategy for innovative development of the Russian economy for a given time horizon, taking into account changing resource constraints, suggests that there are several acceptable alternatives and decision rules, which allow to compare the quality of alternatives. Variants of innovative development of the economy are constructed as a combination of multi-criteria expert assessments of the model elements. Different decision rules linking the elements of the model are formed by the decision maker (DM) or the head of the planning body. The decision rule is an algorithm of moving from the directive goals of the planning body to the sets of tools and resources necessary to achieve the goals. The decision rule is constructed by sequentially selecting, at each level of the structure, of the subsets of the model elements ensuring the implementation of the elements of the upper level.

The selection of elements and their inclusion in the "supporting subset" is based on the preferences of the planning body or decision maker. Depending on the specifics of the problem being solved, various methods of forming a "supporting subset" can be used, for example, by setting certain estimates by criteria for innovations. At the same time, each policy option will have its own set of tools and resources necessary to implement the policy, and its own set of mechanisms that contribute to the achievement of goals. As a result, several qualitatively different development scenarios can be obtained. For the final comparison of options, it is necessary to use other methods, in particular, to analyze the coincidences and differences of "providing subsets" for selected innovations, to assess the degree of different mechanisms' impact on the goal achievement. According to the analysis and comparison of scenarios, lists of problems that need to be solved are formed for promising directions of research, educational programs, legislative activities, etc., ensuring the innovative development of the economy.

The choice of alternative options for innovative development can be considered as a two-way process in which the transition takes place either from the current state to a possible future one (“direct process”), or from the required future state to the current one (“reverse process”). The “direct process” - the so-called bottom-up planning – starts from the capabilities currently available and goes into the state determined by the “natural” course of events in the process of implementation with traditional resources. The “reverse process” - the so-called top-down planning – starts from the needs (that is, the desired future state) and goes through element-by-element decomposition into a list of measures and resources necessary today to achieve the desired state, if it is possible.

Sometimes, direct and reverse planning processes are also referred as research and normative approaches, respectively. The normative approach is used when it is necessary to structure the problem as a whole, take into account the requirements of the external environment of the system, the goals of the planning body. That is why various methods of program planning, focused on solving “breakthrough” revolutionizing problems, it is based on this approach. Techniques based on the research approach do not require usually an exhaustive structuring of the problem. In this case, the choice of a development strategy can be reduced to the selection of the most significant research results within the framework of any policy.

The multilevel information-logical model of the scientific and technological potential allows us to “pass” through the hierarchical structure in different directions: top-down (from the given goals to the most appropriate set of means to achieve them); bottom-up (from disposable resources to possible goals); from the middle (from any level up to the goals and down to more detailed means). The model provides opportunities to identify: basis innovations that influence at the formation of new economy sectors and possible markets; improving innovations affecting the development of many economy sectors and existing markets; unique breakthrough and promising technologies with the potential for rapid distribution and application; replacing technologies and removable high technologies. Using such tools allows us to explore innovative processes within a single system of interrelated goals and means to achieve them in the production, implementation and dissemination of scientific knowledge, clarify the role of elements of the national innovation system in the transfer of knowledge and technology, evaluate the effectiveness of the impact of scientific and innovation activities on the economic development of the country.

4 Conclusions

We proposed a scientific and methodological toolkit for building multilevel information-logical structures that is based on the methodology of verbal decision analysis and aimed at the analysis of various strategies to achieve the goals of national innovation policy. The best or acceptable goals of innovation development and the most appropriate means to achieve them, provided with appropriate resources, are selected on the basis of multi-criteria expert assessments of the model elements and intensity of connections between elements at different levels. The numerical coefficients of the criteria importance and the numerical factors of the options value for strategic decisions are not calculated, as well as the qualitative estimates are not converted into any numerical indicators. The final results are described by verbal attributes, convenient to understand in natural language familiar to humans.

Multilevel information-logic modeling can be used in the development of forecasts, programs, plans for solving three types of problems: the determination of a collection of the means necessary to achieve the given goals (a choice of the subset from the existing set of means ensuring the achievement of the specified goals); the analysis of resource allocation options (a definition of a set of goals that can be achieved with available resources); the analysis of the possibility to achieve the given goals under the specified resource constraints. The proposed approach allows us to find the best collection of goals and means, that is, in a multi-criteria sense, the best option for a development strategy with available resources.

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