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A D Ulyev[1], S V Pronichkin[2,3], A V Kholstov[4] and I B Mamai[5]

[1]Volgograd State Technical University, 28, Lenina Avenue, Volgograd, 400005, Russia
[2]Federal Research Center "Computer Science and Control" of Russian Academy of Sciences, 40, Vavilov Street, Moscow, 119333, Russia
[3]National University of Science and Technology "MISiS", 4, Leninsky Prospect, Moscow, 119049, Russia
[4]N.N. Semenov Federal Research Center for Chemical Physics Russian Academy of Sciences, 4, Kosygina Street, Moscow, 119991, Russia
[5]Federal Center of Theoretical and Applied Sociology of Russian Academy of Sciences, 24/35, Krzhizhanovsky Street, Moscow, 117218, Russia

E-mail: ibmamay@yandex.ru

Abstract. Scientific and technical programs are an important means of implementing the priority directions of the science and technology development. The key features of scientific and technical programs for the formation of demand and supply for scientific knowledge are considered, the classification of the programs main types is carried out. Criteria for assessing the potential and activity of the scientific and technical programs actors were developed. Dynamic models of the system analysis of the scientific and technical programs actors' absorption capacity according to many criteria based on the data envelopment analysis methodology are proposed.

1. Introduction

Innovation implies the introduction of new organizational and technological means based on scientific developments. The assessment of absorption capacity allows to assess the technical and organizational feasibility of introducing scientific results into production. Moreover, at any stage of implementation, the use of independent expert assessments is permissible. This fully applies to the results of scientific and technical programs, albeit justified from one side or another in the course of competitive procedures and scientific developments; but this is not the reason to unconditionally introduce the results obtained into production. Because in the course of scientific development, mistakes can be made; in the course of practical implementation, it often turns out that the new technique or technology use effect depends on some factors not taken into account by the developers. Therefore, it is necessary to evaluate individual characteristics of the absorption capacity in the process of deciding on any scientific development results implementation: the practical significance and novelty of the result, to determine the possible timing and scope of implementation, the ability of consumers to master the result, the possible scale of the results use, etc.

It is important to note that the scientific validity of the decisions made on the scientific and technical activities results implementation is determined by the models used and algorithms for their

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expert assessment. The absorption capacity of the results is largely determined by the specific type of program.

2. Main characteristics of scientific and technical programs

Scientific and technical programs (STP) are an important means of implementing the priority directions of science and technology development. There must be a substantial concentration of research resources within programs. Long-term strategic directions for the development of science are being implemented within the framework of STP. The choice of these areas is a difficult task, the solution of which largely determines the effectiveness of the scientific and technical progress implementation. The formation of the research strategic directions can be implemented within the framework of the Foresight method [1, 2]. Within the framework of the STP, it is planned to carry out a large number of projects annually, having a versatile topic and having a different impact on the improvement of the national innovation system (NIS) individual elements.

Within the framework of the scientific and technical progress, project financing and (or) institutional financing can be carried out when support is provided not only for a group of researchers, but laboratories and even entire scientific and educational organizations. The program can be focused on specific consumers, on the development of institutions or on the solution of broader tasks. The STP diversification takes into account several different areas, and specialization focuses on specific interrelated areas. Large-scale projects guarantee greater involvement of public resources and participation of various partners, but at the same time, the deployment of such projects is more time consuming than for small projects. The program can be focused on supporting basic research, applied research, or innovation. The direction of STP research can be set by the end user and reflect the demand for new knowledge. The program can be focused on long-term strategic projects that consist of several stages or on the implementation of short-term projects. Top-down and bottom-up procedures can be used to form STP directions [3, 4]. The top-down approach of the directions formation is, as a rule, the scientific research areas definition by the state, in the area of its traditional responsibility. In the case of the directions formation from the bottom-up, it is already necessary for business and science representatives not only to formulate, but to justify and convince the customer of the scientific and technical progress of their necessity. The most influential and well-known scientists can be attracted to participate in the program, while, as a rule, support is provided for areas in which there is a significant backlog and the scientific results obtained are mainly of an evolutionary nature. At the same time, the attraction of new still little-known research teams in some cases allows to get a revolutionary scientific result.

The considered characteristics determine the specific type of STP.

STP for a scientist. The scientist is allocated an amount to conduct research at his discretion. He must set the research goal, choose its direction, develop a plan for the implementation of the research and ways of its implementation. In this case, one can get new knowledge that will allow to make a big step forward in a certain field of knowledge and their practical implementation. However, results with a low absorption potential can be obtained, which at present cannot give anything to practice.

STP for a scientific direction. The scientific and technical council, consisting of administrators and potential executors of the program, determines the research directions. Compared to the first case, the range of research directions is noticeably narrowed, and in this case the final result is concretized to some extent and the timing of the completion of the research and practical implementation are quite clearly defined.

Target STP. In this case, the direction and specific goal of the program activities are determined, the final result of the study, the timing of the stages and completion of work are formulated. In other words, the result and terms of its creation and practical implementation are stipulated.

When creating the results of STP, their practical implementation, considerably valuable, and sometimes even cardinal, decisions often arise. There is a need for additional research and significant technological innovations.

3. Criteria for assessing the STP actors' absorption capacity

The implementation of scientific developments obtained in the course of the STP implementation, as a rule, requires certain changes in technique, technology and organization of production. The effect of the STP implementation is generally characterized by their effectiveness in social, environmental, scientific and technical, investment, production, financial, and other spheres. In the general case, the STP program result effectiveness is the category that expresses the correspondence of the results and the costs incurred to certain goals and interests. It is proposed to consider the assessment of the STP actor's absorption capacity as the initial stage of the investment innovation project aimed at achieving the ultimate goal - the production of final products or (more generally) meeting the needs of these products final consumers.

The investment innovative project for the implementation of the STP results will be successful [5, 6] if the actors of the NIS have the ability to absorb them. The indicators for assessing the absorption capacity can be a set of indicators of a different nature. This description was applied to countries [7] and included technical and managerial competencies, infrastructure of the country and its institutions. There are papers that analyzed the absorption capabilities of organizations [8, 9] and individual technologies [10]. In these papers, specific problems are identified due to technological and non-technological factors. Institutional and organizational changes are then proposed that are necessary to absorb the new technology. At the same time, each of the components of the absorption capacity requires the development of independent criteria. All of them should form a single system that will allow for the aggregation and ranking of STP actors. Aggregation and ranking will allow to get the values of indicators of a higher level. Such a system of criteria will make it possible to assess certain aspects of the possibility of the scientific and technical progress results implementing. For example, feasibility is one of the characteristics of absorption capacity and means that all necessary technical, environmental, social, financial and other constraints are met. Accordingly, feasibility can be assessed from different points of view - technical, technological, economic, environmental, etc.

To assess the absorption capacity, a hierarchical system of criteria is proposed, which could, from a systemic standpoint, give an idea of various aspects of the absorption capacity. The system includes two groups of criteria characterizing the potential and activity of actors. Potential includes three groups of criteria that take into account financial, personnel and logistical support.

Activity includes seven groups of criteria.

The first and second groups reflect the nature and type of the STP result.

The third group of criteria takes into account the contribution of the result to the achievement of the most important target indicators and indicators of STP.

The fourth group of criteria assesses the contribution of the scientific and technical progress results to the solution of social problems.

The fifth and sixth groups of criteria allow to assess the relevance and feasibility.

To assess the readiness of the scientific and technical progress results consumers, the seventh group of criteria is intended.

Criteria of potential and activity allow to justify certain technical, technological or financial design solutions. For example, investors will be able to get information about the possible demand for the result; lenders will be able to confirm the validity of determining the need for credit resources, studying such an aspect as the availability of funds for the result development, it is possible to obtain information about the possible scope of the result usage, the scale of its application, scientific and technical significance.

4. Methodology for assessing the scientific and technical programs actors' absorption capacity

Currently, there is no generally accepted methodology for assessing the absorption capacity of actors in scientific and technical programs. Additional difficulties arise when R&D are assessed that have a high degree of risk and uncertainty of the final results, which is typical for the results of scientific and technical programs. The existing methods for assessing the effectiveness of projects uses the so-called cost approach based on the numerical measurement of financial indicators [11]. However, despite the seeming simplicity and obviousness, this approach is not very suitable for working with the characteristics that evaluate the scientific results of STP. Science and technology programs are composed of many interrelated elements. Such systems actors effectiveness evaluation should be carried out taking into account their dynamic and complex characteristics. The existing approaches to the development of models for assessing the effectiveness of scientific and technical systems, based on the principles of the data envelopment analysis (DEA) [12], are limited by the generality of their modeling. The existing DEA models represent a measure of the system efficiency in the case of multiple inputs and outputs, but they do not take into account the processes of complex systems change over time. In practice, nonparametric DEA models, in which there is no production function between the inputs and outputs of the system, are used more often than parametric models [13]. At the same time, the information characterizing the internal structure of complex scientific and technical systems is not taken into account in the DEA models, which can lead to overestimated or underestimated indicators of the scientific and technical programs actors' absorption capacity. To level these shortcomings, it is advisable to use network DEA models that use intermediate variables [14]. The intermediate variables, obtained at the previous stage of the scientific and technical system functioning, become the input variables of the next stage. Intermediate variables are formed in one period of time, and become a source for the growth of absorption capacity in the next period. In the existing network models, the results of the scientific and technical system functioning, obtained in the current period of time, do not depend on the previous one. With regard to the assessment of the STP actors' absorption capacity, the intermediate results of which are interrelated, the one-step DEA model is not suitable, and a dynamic model is required. In complex scientific and technical systems, network and dynamic DEA models cannot work independently, and therefore special joint dynamic network DEA models are needed to assess the absorption capacity of actors.

There are two main approaches to the development of dynamic network DEA models, forward and backward. The reverse approach is based on special network slices of information [15], this approach is sensitive to the accuracy of the initial data and is computationally laborious. The direct approach is more resistant to distortions of the initial data and, from a computational point of view, is less laborious [16]. To use direct and inverse methods, it is necessary to preset a set of weighting coefficients for the system efficiency criteria, which creates certain difficulties for decision-makers. In addition, a predetermined set of weights is common for all the complex scientific and technical system elements, which does not allow taking into account the importance of an individual element of the system in dynamics.

A new approach to the development of dynamic network DEA models for the analysis of the STP actors absorption capacity is proposed. Existing approaches to the analysis of complex scientific and technical systems are based on a predetermined vector of weighting coefficients. At the same time, the complex systems effectiveness assessments are very sensitive to changes in weight coefficients, and in practice it is quite difficult to set weight coefficients for all elements of the system. Usually, a common set of weighting factors is used for all the assessed elements of the system, which does not allow considering the importance of each element of the scientific and technical system. In the proposed approach, a set of weighting factors is determined based on the analysis of various prospects for the development of the scientific and technical system. This approach to modeling differs significantly from the existing ones, since it is the STP actors absorption capacity overall assessment decomposition based on the relationship between the criteria of activity and potential.

Let the scientific and technical system consists of n actors $(i=1,\dots,n)$, which implement STP projects p $(p=1,\dots,P)$ for T periods $(t=1,\dots,T)$. The criteria characterizing the potential are denoted by $X^{(t)}_{j^p i}, (i^p=1,2,\dots,m^p)$, and the activity of actors - by $Y^{(t)}_{r^p i}, (r^p=1,2,\dots,z^p)$. Intermediate variables are denoted by $S^{(t-1,t)}_{d^p i}$, $(t=1,2,\dots,T+1;\, d^p=1,2,\dots,q^p;\, p=1,2,\dots,P)$ and $S^{(t)}_{d^{(p-1,p)} i}$, $(t=1,2,\dots,T;\, d^{(p-1,p)}=1,2,\dots,q^{(p-1,p)};\, p=1,2,\dots,P+1)$. The criterion importance coefficients $X^{(t)}_{j^p i}$, $Y^{(t)}_{r^p i}$, $S^{(t)}_{d^{(p-1,p)} i}$ are denoted by w_{i^p}, u_{r^p}, l_{d^p}. Then the general potential and activity of STP actors during periods can be presented in the following form.

$$\sum_{p=1}^{P}\sum_{t=1}^{T}\sum_{r^p=1}^{z^p} u_{r^p} Y_{r^p i}^{(t)} + \sum_{p=1}^{P}\sum_{p^p=1}^{q^p} l_{d^p} S_{d^p i}^{(T,T+1)} \tag{1}$$

$$\sum_{p=1}^{P}\sum_{t=1}^{T}\sum_{j^p=1}^{m^p} w_{j^p} X_{j^p i}^{(t)} + \sum_{p=1}^{P}\sum_{p^p=1}^{q^p} l_{d^p} S_{d^p i}^{(0,1)} \tag{2}$$

After analyzing various prospects for the development of the scientific and technical system, the optimal values of the coefficients were found $w_{i^p}^*$, $u_{r^p}^*$, $l_{d^p}^*$ the total absorption capacity of the STP actors takes the following form:

$$AC_i = \frac{\sum_{p=1}^{P}\sum_{t=1}^{T}\sum_{r^p=1}^{z^p} u_{r^p}^* Y_{r^p i}^{(t)} + \sum_{p=1}^{P}\sum_{d^p=1}^{q^p} l_{d^p}^* S_{d^p i}^{(T,T+1)}}{\sum_{p=1}^{P}\sum_{t=1}^{T}\sum_{j^p=1}^{m^p} w_{j^p}^* X_{j^p i}^{(t)} + \sum_{p=1}^{P}\sum_{d^p=1}^{q^p} l_{d^p}^* S_{d^p i}^{(0,1)}} \tag{3}$$

Taking into account the restrictions on the scientific and technical system and its actors effectiveness value, the STP network model of the absorption capacity multi-criteria analysis can be written in the following form:

$$E = \max_i \frac{\sum_{p=1}^{P}\sum_{t=1}^{T}\sum_{r^p=1}^{z^p} u_{r^p} Y_{r^p i}^{(t)} + \sum_{p=1}^{P}\sum_{d^p=1}^{q^p} l_{d^p} S_{d^p i}^{(T,T+1)}}{\sum_{p=1}^{P}\sum_{t=1}^{T}\sum_{j^p=1}^{m^p} w_{j^p} X_{j^p i}^{(t)} + \sum_{p=1}^{P}\sum_{d^p=1}^{q^p} l_{d^p} S_{d^p i}^{(0,1)}} \tag{4}$$

$$\begin{cases} \dfrac{\sum_{p=1}^{P}\sum_{t=1}^{T}\sum_{r^p=1}^{z^p} u_{r^p} Y_{r^p i}^{(t)} + \sum_{p=1}^{P}\sum_{d^p=1}^{q^p} l_{d^p} S_{d^p i}^{(T,T+1)}}{\sum_{p=1}^{P}\sum_{t=1}^{T}\sum_{j^p=1}^{m^d} w_{j^p} X_{j^p i}^{(t)} + \sum_{p=1}^{P}\sum_{d^p=1}^{q^p} l_{d^p} S_{d^p i}^{(0,1)}} \le 1 \\[2ex] \dfrac{\sum_{r^p=1}^{z^p} u_{r^p} Y_{r^p i}^{(t)} + \sum_{d^p=1}^{q^p} l_{d^p} S_{d^p i}^{(t,t+1)} + \sum_{d^{(p,p+1)}=1}^{q^{(p,p+1)}} l_{d^{(p,p+1)}} S_{d^{(p,p+1)} i}^{(t)}}{\sum_{j^p=1}^{m^p} w_{j^p} X_{j^p i}^{(t)} + \sum_{d^p=1}^{q^p} l_{d^p} S_{d^p i}^{(t-1,t)} + \sum_{d^{(p-1,p)}=1}^{q^{(p-1,p)}} l_{d^{(p-1,p)}} S_{d^{(p-1,p)} i}^{(t)}} \le 1 \end{cases} \tag{5}$$

In contrast to the existing approaches, the proposed approach does not require a preliminary specification of a set of weighting coefficients to obtain generalized estimates of the scientific and technical system actors effectiveness. Moreover, the proposed modeling approach is applicable to both radial and non-radial measures.

5. Conclusion

The proposed scientific and methodological approaches and the system of criteria represent a transparent mechanism for assessing and analyzing the absorption capacity of STP actors in expert and intelligent decision support systems. The developed dynamic model of the data envelopment analysis allows determining the effectiveness of the integrated scientific and technical system actors without preset weighting factors. The proposed approach is focused on assessing the potential and scientific and technological progress actors activity characteristics, which will allow to make a scientifically

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grounded decision on the implementation of scientific results. Evaluation criteria will justify certain technical, technological or financial design solutions.

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References
[1] Georghiou L and Harper J 2011 *Futures* **43** 243-51
[2] Hilbert M, Miles I and Othmer J 2009 *Technological Forecasting and Social Change* **76** 880-96
[3] Riemann H, Bluhm T and Zilker M 2009 *Fusion Engineering and Design* **84** 1598-601
[4] Blados W 1991 *Government Information Quarterly* **8** 135-53
[5] Cardoso H, Goncalves A, Carvalho G and Carvalho H 2020 *Evaluation and Program Planning* **80** 101797
[6] Grillitsch M, Hansen T, Coenen L, Miorner J and Moodysson J 2018 *Research Policy* **48** 1048-61
[7] Kotabe M, Jiang C and Murray J 2011 *Journal of World Business* **46** 166-76
[8] Wang Z, Ling J and Chok J 2020 *Journal of Engineering and Technology Management* **57** 101587
[9] Duong V 2020 *International Economics* **163** 44-57
[10] Mahmood T and Mubarik M 2020 *Technological Forecasting and Social Change* **160** 120248
[11] Roth T and Spieth P 2019 *Journal of Business Research* **101** 83-92
[12] Ghiyasi M and Cook W 2020 *Omega* **9** 102385
[13] Guo C and Zhu J 2017 *European Journal of Operational Research* **258** 398-400
[14] Peykani P, Mohammadi E and Emrouznejad A 2020 *Expert Systems with Applications* **166** 113938
[15] Kalantary M and Saen R 2018 *Computers & Industrial Engineering* **135** 1224-38
[16] Henriques I, Sobreiro V, Kimura H and Mariano E 2020 *Expert Systems with Applications* **161** 113632