Modeling of Research Processes' Automation

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Abstract: An algorithm for trajectory implementation of scientific research management strategy was developed. Simulation was carried out using the specified algorithm. The calculations were performed using the developed model. It is found that it was advisable to analyze the trajectory of a managerial strategy as a certain realizable trajectory of management carried out within the boundaries of the hypersurface region surrounding the trajectory of optimal management. It was found that the distance from the optimal management trajectory, which determines the region of acceptable values, is estimated by the quality of management -ρ, which is the aggregate statistical value of the "distance" of the real trajectory from the optimal one. The developed model for management strategy realization of research process when solving a scientific problem, taking into account real conditions based on a digital model, allows for the development of a computer program. The program allows you to calculate quickly the trajectory of optimal control of research process according to a given strategy, evaluate the quality of management and present ways of optimal control taking into account the real conditions of research process.

1 INTRODUCTION

Science is the most efficient area for investment. Currently, in world practice it is generally accepted that the profit from investments in science amounts to 200% (Ryzhakova, Manakhov, 2013). Every year, R&D expenditures increase worldwide. Over the past 50 years, the amount of new knowledge increased approximately two to three times, while the volume of information about research results increased eight to ten times, and the amount of funds allocated to R&D increased more than 100 times. For example, in the United States, the ratio of science spending to gross domestic product (GDP) in 2018 was 2.74%, in 1950 it was only 1%. In China in 2018 this indicator was 2.12% and in 1996 it was only 0.6%. Russia ranked the 34th with a rate of 1.04%. Russia's position is even lower in terms of domestic research expenditure per researcher (in full-time equivalent), the country ranked the 47th ($93,000). The Switzerland ranked the first ($406,700), the United States ($359,900) ranked the second (Ryzhakova, Manakhov, 2013).

Research shows that neither gross expenditure nor per researcher R&D expenditure indicators provide any country with results that can be assessed as "leading positions in world science". The volume of accumulated investments in R&D over long periods, the development of scientific schools and experience in R&D could more likely serve as such an indicator. These factors explain, for example, the leading positions of scientists in Great Britain (70 Nobel Prize laureates), which spends funds comparable to those of the Russian Federation on a range of scientific research projects (Podosokorsky, 2019).

The experts from the Institute of Control Sciences of the Russian Academy of Sciences say, "When we talk about science management, we must understand that scientific and technical developments are the most important subject of management. Without competent research management, it is impossible to build a new digital economy." A scientifically based

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set of measures is needed to improve the regulatory, legal, and methodological framework for scientific and technological sphere management (Ryzhakova, Manakhov, 2013; Shchedrovitsky, 2019; Horvat, 2019).

The effectiveness of scientific and technological development is determined not only by quantitative indicators of scientific and technological potential. Science became a special sphere of activity. Global forms of organization penetrated it, and a system of science management and administration were established (Ryzhakova, Manakhov, 2013; Shchedrovitsky, 2019; Horvat, 2019). The problem lies in the discrepancy between the established system of scientific research management and the requirements of scientific and technological development.

The analysis of theoretical and cognitive principles of the researcher's activities in developing a strategy for scientific research has a decisive influence. Despite the diversity of approaches to the formation of science management strategies in different countries, they show fairly common factors in choosing priorities. This can be considered as an indicator of the emerging unity of views on the concept and principles of a strategy aimed at technological shifts and innovations, as well as their role in economic growth (Gassler, Polt, Schindler, 2004).

The tasks of efficiency growth of funds allocated for R & D use are connected with the standardization of the work of researcher, which allows justifying the planning of research work and the costs of its implementation. Labor standards are one of the most important incentives and should form the basis of the system of productive work encouragement of scientific researchers. However, the issue of standardization of research in the scientific community remains open and controversial, since the validity of the established standards can only be objectively assessed taking into account all of its specific features (Feoktistova, 2014; Kushnir, 2010). The Presidium of the Russian Academy of Sciences plans to resolve issues related to the development of proposals for the development of criteria and effectiveness growth of Russian science.

The solution of a set of problems related to efficiency growth of R & D led to the development of the corresponding standard. Clause 4.4 of the standard regulates "the choice of a research direction in order to determine the optimal variant of research based on the analysis of the state of the problem under analysis, including the results of patent research, and a comparative assessment of possible solutions taking into account the results of predictive research conducted on similar problems". From the given version of the key point of the Government Standard (GOST), it is very difficult to determine clearly with sufficient accuracy how to find the optimal variant of research direction.

The main goal of science is the production of new scientific knowledge and its use in science and practice. The indicators of achievement of the main goal are the results of scientists' work. The direct product of scientific activity has informative value. Management of social systems, including science, is carried out with the help of a decision-making mechanism. Decisions are made on the basis of evaluation (measurement) of various parameters of the system and, above all, the efficiency of its functioning (Libenzon, 1987).

The experts say, “Today, an important problem is not only and not so much the use of a computer as a research tool, but the use of information technologies to improve the efficiency of scientific activity management. New technologies can become a serious help in such areas as planning and analysis of scientific activity results.” Therefore, the goal of automation of scientific activity should consist in the reduction of the share of routine in the scientist’s activity by automating the process of tracking current publications (Emelyanov, 2020).

Since 2008, the Information and Analytical System for Supporting Research (IAS) has been in operation at St. Petersburg State University. It contains information on all current research projects implemented by employees and departments of St. Petersburg State University. Registration in the IAS is mandatory for all research projects. The following tasks are solved with the help of the IAS: planning of research activities; record of research results; analysis and forecasting of activity results; management of research.

The introduction of a new method into production requires certain costs, and it is often necessary to increase the efficiency of the process by at least a certain amount, at which this introduction becomes justified. If each experiment is sufficiently complex and labor-intensive, the task of minimizing the number of such experiments arises, provided that the hypothesis is confirmed with a given confidence probability. When using the method of sequential analysis, mathematical processing of the results is made after each experiment. As a result of this processing, it is determined whether one of the competing hypotheses (and which one) can be accepted or whether research can be continued (Wald, 1960; Walker, 2019). Hypothesis testing, the theory

of statistical estimates, and experimental planning issues can be studied within this theory as necessary stages of a set of works.

Possible options for working strategies' creation in the Russian Federation based on forecasting are being discussed. The Presidium of the Russian Academy of Sciences notes that "there are about 20 models of economic development in the world, but their results vary. It is important to come to a consensus and agree on all the parameters used in creation of these models. The methodological basis of mathematical modeling is not agreed upon. Therefore, mathematical models give different results." The problem is the lack of tools for decision-making. "99% of Russian strategies cannot be implemented because they do not contain quantitative estimates presented in forecasts".

In this regard, it is appropriate to recall that strategic management presupposes: a goal; a special way to achieve the goal; a plan for achieving the goal; resource provision; innovative focus as a way to achieve the goal. The goal, as a planned controlled result, should be linked to real capabilities of the managed system. Real capabilities are usually understood as quantitative characteristics. However, the activities of all regions, enterprises and other entities are also characterized by qualitative characteristics (quality of resources, quality of management, natural conditions, etc.). To determine unambiguously the priority direction of research process, automate it, digital models are needed that allow for an unambiguous justification of the strategy of scientific research, taking into account not only quantitative but also qualitative characteristics.

The aim of the study is to develop a model for the unambiguous definition of a research process management strategy based on quantitative assessments when a scientific problem solution in the context of innovative development, taking into account real conditions (Borovik, 2013).

Objectives are as follows: 1. To study the possibilities of quantitative assessment to justify the choice of strategy for a scientific problem solution; 2. To visualize the strategy for a research problem solution based on a spatio-temporal model. 3. To suggest a model for the developed strategy of research process management when solving a scientific problem, taking into account real conditions based on a digital model.

2 METHODOLOGY OF RESEARCH

The experts from Gartner, a research and consulting company specializing in information technology markets say, "We are no longer facing a technical evolution, but a real technological revolution that is sweeping away all the remnants of pre-digital times".

Digitalization is a process management tool. This means a tool for realization of all management functions: planning, organization, accounting and control. It should be emphasized that this refers to technical, economic, social, research and other processes (Ciarli, Ràfols, 2019).

Research shows that the lack of experience in scientific analytics of production parameters is the main obstacle to benefits' achievement of analytical solutions' use in production. At recent conferences, many innovations in the field of IT and transportation were demonstrated. New digital products were created, a single digital space of the EAEU and CIS countries is being formed, international relations in the transport industry are being strengthened in the nearest and medium term.

As practice shows, 40% of companies believe that digitalization of production can reduce operating expenses (OPEX) by 16% or more. The potential for achievement of high returns on industrial assets with a constant focus on operational efficiency improvement, as well as a holistic strategy for asset optimization and a pragmatic instruction for action is extremely attractive for an industry on the threshold of changes in business and technology (Moreno, 2018).

Digitalization has wide use, first of all, in strategy development for processes and their monitoring. The existing experience in strategies' development shows that the existing methods for forecast calculations do not fully satisfy the current conditions. Consequently, it is difficult to formulate a goal clearly, what means it is impossible to develop an effective strategy. As a consequence, it is difficult to determine the effectiveness of using funds allocated for innovative development.

In this regard, one of the primary tasks of digitalization is a sufficiently accurate and prompt numerical determination of forecast characteristics in the context of innovative development, taking into account real conditions. Maximum automation of the solution of a set of problems is achieved by digitalization of management process.

Digital modeling is widely used in scientific research. A significant difference of the current period in digital models' use is their wide application

as a forecasting tool based on computers and the Internet. Analytical forecasting of processes using digital models allows having scientific foresight as a result of the study, i.e. the basis for making a decision on specific ways of production or another process.

The apparatus of digital models is appropriate to use in planning and forecasting various processes, which allows determining an effective combination of factors to achieve the maximum result. A digital model can be seen as dynamics of the simulation of main technical production and other factors on the parameter under analysis. Formally, most digital models belong to the class of statistical ones. The process of functioning of any material object is a sequential change of its states in time, each of which determines specific values of some physical quantities.

In a digital model, private and individual features of an object or process are always smoothed out, and general identified features are recorded on the basis of repeatability. Research into digital models in space and time is very promising due to the possibility of significant accuracy growth of the desired parameters determination (Borovik, Borovik, 2016).

The accuracy of the digital model is determined by errors in factors' determination and calculation errors in geometric modeling. The use of similarity theory makes it possible to increase the accuracy of mathematical digital models by presenting output information in a criteria form, which allows the results of calculations to be extended to groups of similar phenomena.

Digital models use various forms of expression and units of measurement of dependent and independent variables. Variables can be presented: absolute values and in natural units of measurement; absolute values in monetary terms; relative dimensional values; relative values of dynamics and structure, for example, growth rates, indices, shares. Uniformity of expression of dependent and independent variables should be sought (Ergunova, Skuratov, Pozdeeva, 2019). A digital model is an initial model in management calculations and allows finding the optimal option for using real opportunities. Digitalization creates the prerequisites for more complete use of the potential of modern computing technology in order to obtain objective information on effectiveness of the process under analysis and forecast the results of its development. A standard set of computer software includes all the necessary tools for calculations by means of digital models. Based on such calculations, it is possible to obtain specific indicators that allow forming a well-founded strategy for scientific and technological developments.

Modeling the process of numerical solution of a mathematical problem on a digital computer practically means its automatic solution by means of a digital computer.

If a mathematical description of the functioning of the original object is known, according to this description a process over numbers expressing the values of quantities characterizing the state of the object is defined, and this process is displayed in a digital computer, then the process realized by the digital computer is a material functional formal mathematical digital model similar to the original one.

Strategy modeling for the solution management of a research problem

A strategy for a research problem solution is understood as a plan of action coordinated according to aggregated indicators in space and time, which in a certain way (innovative component) ensures the achievement of the main goal based on adequately used conditions and means (Borovik, 2011).

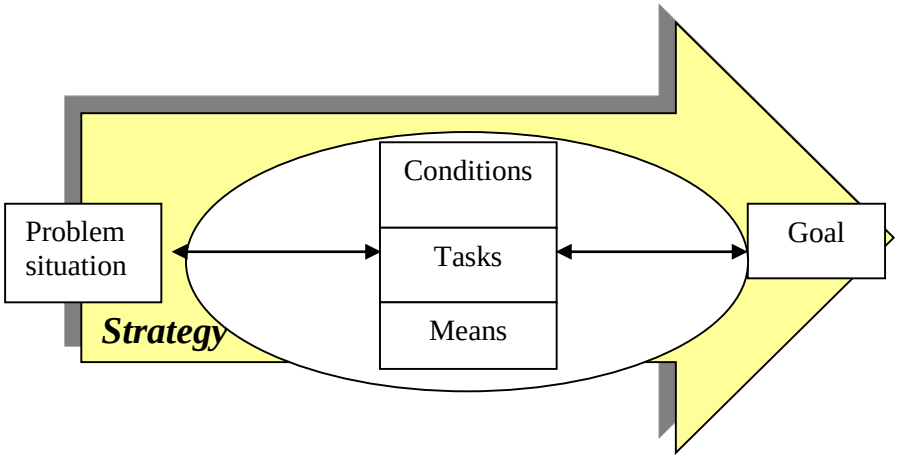

Figure 1: Scheme of Strategy Based Management.

The necessity to solve a research problem is associated with the emergence of a problem situation. Objectively, the emergence of a problem situation is due to the process of development of production and progress (Stoll, 1967). In order to get rid of a problem situation, it is necessary that each finite set of available factors A corresponds to a finite set of necessary factors B, ensuring the solution of the problem. Then we write

$$A \sim B, \quad (1)$$

If the sets An do not intersect each other, i.e.

$$A_n \bigcap A_{n|} = \varnothing \quad \text{at} \quad n \neq n^{/}, \quad (2)$$

and the sets Bn also do not intersect each other, i.e.

$$B_n \bigcap B_{n^{э}} = \varnothing \quad \text{at} \quad n \neq n^{/}. \quad (3)$$

For each n An~Bn . Then to every

$$a_0 \in \bigcup_{n=1}^{m} A_n \quad (4)$$

corresponds to a single element

$$b_0 \in \bigcup_{n=1}^{m} B_n. \quad (5)$$

If, according to some rule, each element of set A can be associated with one and only one element of set B, and each element of set B will be associated with one and only one element of A, then

$$\bigcup_{n=1}^{m} A_n \sim \bigcup_{n=1}^{m} B_n. \quad (6)$$

Achievement of a one-to-one correspondence (6) through the implementation of a number of activities related to problem solution in time may indicate a solution of a problem situation.

One of the first stages of research is the analysis of the results of previous research in space and time. As a result of such analysis, factors x that affect the target indicator Y are identified. In general, the task is to influence the factors to achieve the desired result of the target indicator. As a rule, we are talking about finding the highest or lowest value of the function, for example, bearing capacity growth of an engineering structure, maximum profit or for example reduction of accidents (Silyanov, Domke, 2016; Borovik, Lukin, 1995). Statistical information from research reflecting the values of factors and target indicators obtained by a number of researchers, using, for example, multifactorial correlation and regression analysis, can be presented using a function for example of the following type :

$$Y = C_0 \prod_{i=1}^{n} x_i^{\alpha_i} \quad . \quad (7)$$

Where Y - target indicator; x_i , $i = \overline{1,n}$ factors influencing Y; α_i, $i = \overline{1,n}$ - degree indicators, characterizing the «input of» x_i into Y; C_0 – coefficient characterizing the influence of factors not taken into account by the model (Borovik, Lukin, 1995). Let's analyze, for example, a digital model:

$$Y=1{,}231\ x_1^{1.331}\ x_2^{1.502}\ x_3^{0.432}\ x_4^{0.231}\ x_5^{0.753}, \quad (8)$$

It should be mentioned that the resulting digital model, for example, (8), describes the hypersurface of a specific process under analysis, which makes it possible to carry out various operations on this surface connected with the optimization of the strategy for the solution of a specific scientific

problem. To facilitate the visualization of the problem solution, we will limit ourselves to a three-dimensional model that includes factors x_1 and x_2, as having the greatest influence on Y. We use a two-factor digital model of the process under analysis, for example,

$$Y=1{,}231\ x_1^{1.331}\ x_2^{1.502} \quad (9)$$

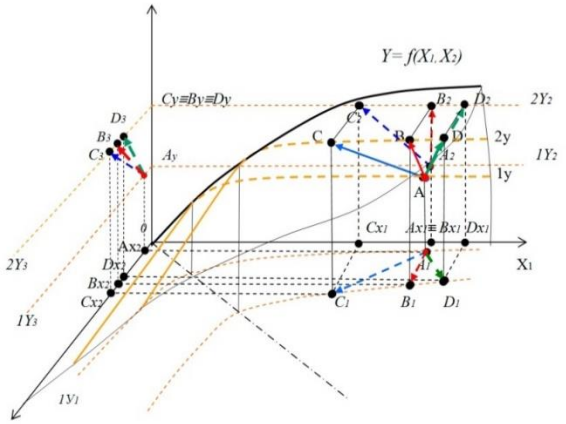

Figure 2: Management strategy visualization.

By assigning different values to x_1 and x_2 we obtain the calculated values of Y. The obtained values allow us to construct a three-dimensional graphical model, for example in Figure 2.

The model illustrates the surface of the process under analysis, which can be used to search for a management strategy, for example, the maximum of Y. The curves 1Y and 2Y are isoquants connecting calculation points with the same values of target indicators. The curve 2Y connects calculation points with the same numerical values of the target indicator, the value of which must be achieved as a result of scientific research. As it can be seen from Figure 2, the same value 2Y can be achieved by an infinite number of combinations of factors x_1 and x_2. For example, the level of target indicator 1Y achieved as a result of previously conducted research is characterized by point A and its projections $A1$, $A2$ and $A3$. Target indicator 2Y from point A can be achieved by means of an infinite number of options.

Let us analyze three variants, for example, B, C and D. Each point is characterized by projections B_1, B_2, B_3, C_1, C_2, C_3, D_1, D_2, D_3 and $Bx1$, $Bx2$, $Cx1$, $Cx2$, $Dx1$, $Dx2$, which determine the parameters of the factors when achieving the value of the target indicator 2Y. As it can be seen from Figure 2, achievement of the target indicator 2Y is accompanied by different combinations of factor values. For example, $OCx1<ODx1$, but $OCx2>ODx2$. Consequently, in the current system under analysis, achievement of 2Y can be obtained by different values of x_1 and x_2. Depending on actual conditions (economic, technical, organizational, etc.), the appropriate values of x_1 and x_2 are selected. From a mathematical standpoint, the optimal variant is AB, since AB is a perpendicular from point A to the overlying isoquant to the tangent at point B and is the shortest distance between the isoquants.

An illustration of a management strategy development for the solution of a scientific problem in development is clearly seen in Figure 3 in projections with numerical marks. There can be an infinite number of management strategy options.

Let us take three of them. For example, option $A_1 D_1 E_1$ with constant values of factor x_1 and constant growth of x_2 ultimately ensures the achievement of goal N.

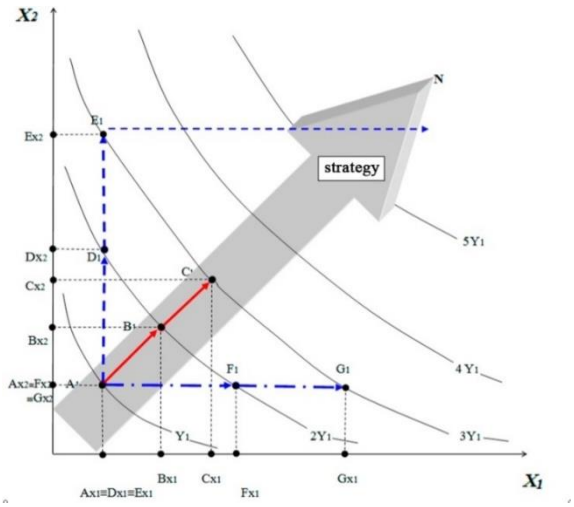

Figure 3: Visualization of strategies in projections with numerical marks.

The strategy along the directions $A_1F_1G_1$ can develop similarly. However, the direction along $A_1F_1G_1$ demonstrates clearly and convincingly that an effective strategy has a different direction, ensuring passage along the shortest distance between isoquants. It should be noted that the digital model, implemented in projections with numerical marks, also reflects the time characteristics of the strategy (Borovik, 2018). For example, the time costs for their implementation can be determined by the distance between isoquants on the same scale for two different strategies.

Let us analyse this conclusion in more detail. Function (8) is determined on the basis of statistical

data. Consequently, the factors in aggregate have information about the target indicator and its changes under the influence of a variety of data, including time. A purposeful change in Y is the result of changes in x_i. The relative position of the isoquant projections, for example in Figure 3, indirectly reflects the spatial and temporal characteristics of the analysis associated with the search for an optimal management strategy. Let us combine the axes used for quantitative characteristics of factors, for example, x_1 and x_2 (formula 9) into one axis OX.

ΔY is the increment associated with the search for the parameters of the target indicator Y under the influence of changing x_i. We get Figure 4, which is convenient for analysis.

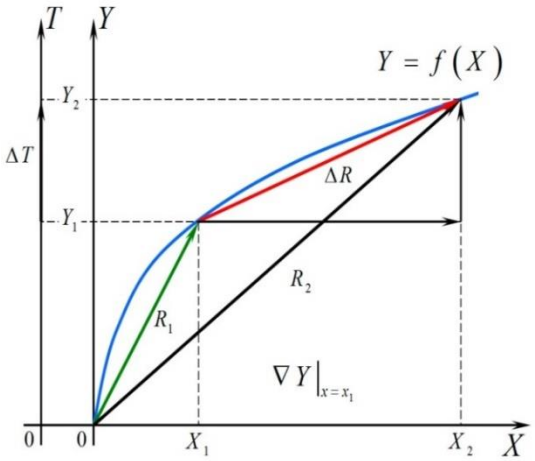

Figure 4: Visualization of research process analysis over time in vector form.

$$\Delta R = R_2 - R_1 \qquad \Delta Y = \Delta R - \nabla Y\big|_{x=x_1} = R_2 - R_1 - \nabla Y\big|_{x=x_1}$$

As this takes place

$$\nabla = \frac{\partial}{\partial x_1} e_1 + \frac{\partial}{\partial x_2} e_2 + \ldots \frac{\partial}{\partial x_n} e_n,$$

what confirms the vector nature of actions related to determination of the target indicator Y, under the influence of factors x_i.

Each point in space is associated with a certain scalar Q, connected with the conditions of research to solve a scientific problem (with the help of economic, technical, organizational and other possibilities). Scalar energy is transformed into vector force by the passage of time (Pan, 2016). Let us turn to the well-known dependence:

$$\Delta Y = Q(t) \cdot \Delta T \qquad (10)$$

where: ΔY – increment of the target indicator associated with reaching the desired target indicator Y; $Q(t)$ – scalar characterizing the conditions of research; ΔT – period of time for implementation ΔY. However, note that ΔY is a vector and Q is a scalar. Then formula (10) should be represented as:

$$\Delta Y = Q(t) \cdot \Delta T \qquad (11)$$

because in order to keep equality in (10) it is necessary that ΔT be a vector (a first rank tensor) (Borovik, Borovik, 2016). A very important conclusion follows from this:

$$\Delta Ti \uparrow\uparrow \Delta Yi. \qquad (12)$$

Vectors ΔTi and ΔYi are collinear and co-directional.

Therefore, to achieve co-direction and collinearity of the vectors ΔTi and ΔYi, it is necessary to ensure a one-to-one correspondence Q′n of technical, economic, organizational or other conditions, given - Qn. This will ensure the optimal time for the implementation of ΔY (Borovik, Borovik, 2016).

$$\bigcup_{n=1}^{m} Q'_n \sim \bigcup_{n=1}^{m} Q_n. \qquad (13)$$

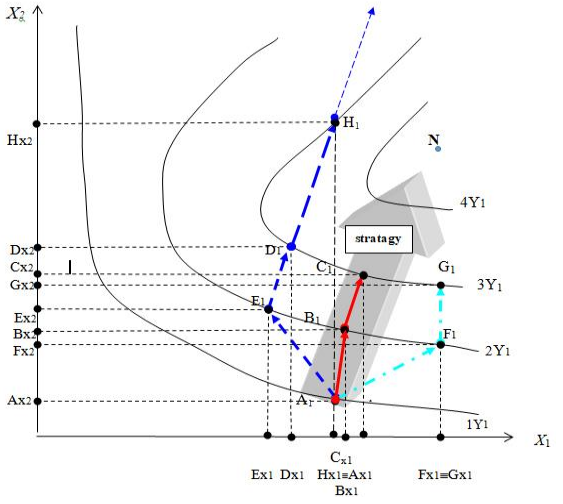

Figure 5: Visualizing of consequences of deviation from the optimal strategy.

It is necessary to illustrate the consequences of the results of the solution of research problem when deviating from the chosen strategy. For example, in Figure 5, the operational control $A_1E_1D_1$ maintains the direction of the strategy, but a shift is allowed due to a significant decrease in the value of the factor x_1, which is visible from the parameters Ex_1 and Ex_2.

Such a shift could be justified by the parameters of the scalar Q. For example, it can be explained by the absence at a time of the corresponding economic, technical or organizational conditions.

The movement to a higher projection of the isoquant $2Y_1$ at point E_1 is provided. However, due to the deviation from the operational control A_1B_1, the strategy will not lead to a positive solution to the scientific problem. The accuracy of the desired parameters calculation using a digital model is characterized by a mean square error of ~5% (Borovik, Borovik, 2016).

When the numeric mark $3Y_1$ is reached, despite the further increase in the values of factors x_1 and x_2 (Hx_1 and Hx_2), the value of the target indicator will decrease, what can be seen from the position of point H_1.

Visualization of the strategy based on a three-dimensional graphical model cannot be considered sufficiently rigorous, since only two factors x_1 and x_2 of the function (8) out of five are used.

However, constructing a three-dimensional model based on the two most influential factors allows us to illustrate clearly the direction of the strategy for the solution of the scientific problem. For a more detailed definition of the strategy, it is advisable to analyze a larger number of factors, using, for example, analytical models, what creates the prerequisites for automating research. The achievement effectiveness of the goal set can be illustrated by the results of the performed studies, for example (Borovik, Borovik, 2016; Borovik, 2018; Borovik, 2017; Borovik, 2017; Borovik, Borovik, 2016).

The relevance of research connected with improvement of the organization of scientific research in order to increase the efficiency of the innovation process is confirmed by recent studies reflecting US policy (Gibson, 2020; Thorp, 2020).

3 RESEARCH RESULTS

Let's turn to dependence (7) $Y = C_0 \prod_{i=1}^{n} X_i^{\alpha_{ii}}$,

We will analyze the optimal management of factors in model (7) to be one that leads, for example, to the maximum of the target parameter Y for each period of time under consideration (Borovik, 2013; Borovik, Borovik, 2016).

Let us consider a managerial procedure that meets the stated objective (Fomichev, 2013). Let us note that the management of research process is of a stage-by-stage nature (Muzgin, 2012). The result of the impact on the object depends significantly on the point in the phase space at which the intervention begins. Consequently, the used control algorithm must necessarily be discrete.

Let the management process be divided into n stages. If we denote the management at the *i-th* stage by *Ui*, and the condition of the system after the *i-th* step by S_i, then it is clear that $S_i = S_i = S_i(S_i\text{-}1, U_i)$. We denote the costs of U_i by C_i. Then, obviously, the approximation of the realized trajectory to the optimal one should be carried out so that

$$C_{\Sigma} = \sum_{i=1}^{n} C_i(S_i, \ldots S_{i-m}, U_i) \to \min,$$

where C_{Σ} - total costs.

Let the initial state of the system be S_0 (note that zero values for X_i are not at all obligatory).

It is required to select $\{U_i\}$, $i = \overline{1,n}$ that

$C_{\Sigma} \to min$ and, in addition, the trajectory of the implemented management would belong to a certain region of the hypersurface surrounding the optimal trajectory. The latter requirement naturally leads to certain restrictions on the variations of factors in management process (Makoto, 2023; Farzaliev, Filippenko, 2022).

Let us denote the costs as C_k at the k^{th} stage, then

$$C_k, k+1, \ldots n = \sum_{i=k}^{n} C_i .$$

If we somehow managed to determine S_n-1, then the task of contol of research process will be reduced to bringing the system from $S_n\text{-}1$ to the "point" S_n in the most economical way. This will be the control of U_n.

Note that U_n will be conditionally optimal, since

$$U_n \equiv U_n(S_n\text{-}1, S_n). \quad (14)$$

Consequently

$$C_n^*(S_{n-1}) = \min_{U_n}\{C_n(S_{n-1}, U_n)\}. \quad (15)$$

It follows that conditional costs $C_n^*(S_{n-1})$ are chieved only with conditional control $U_n^*(S_{n-1})$. Having chosen with the help of $U_n^*(S_n)$, we define the management strategy at the (*n-1*) stage:

$$C_{n-1} \equiv C_{n-1}(S_{n-2}, U_{n-1}); \quad (16)$$

$$S_{n-1} \equiv S_{n-2}, U_{n-1}); \quad (17)$$

$$C_n^*(S_{n-1}) = C_n^*(S_{n-1}(S_{n-2}, U_{n-1})), \quad (18)$$

from which it follows

$$C_{n-1,n}(S_{n-2}, U_{n-1}) = C_{n-1}(S_{n-2}, U_{n-1}) + C_n^*(S_{n-1}(S_{n-2}, U_{n-1})) \quad (19)$$

It is required to define $U_n^*(S_{n-2})$ so that

$$C_{n-1,n}^*(S_{n-2}) = \min\{C_{n-1,n}(S_{n-2}, U_{n-1})\}U_{n-1}.$$

From here we find $U_n^*(S_{n-2})$, which together with $U_n^*(S_{n-1})$ determines the optimal behavior in the region of admissible trajectories.

Continuing with the same idea, we get

$$C^*_{n-2,n-1,n}(S_{n-3}), U^*_{n-2}(S_{n-3});$$

$$C\,C^*_{n-3,n-2,n-1,n}(S_{n-4}), U^*_{n-3}(S_{n-4});$$

.....

$$C^*_{k+1,\ldots,n}(S_k), U^*_{k+1}(S_k)$$

The minimum costs will be

$$C_{k,k+1,k+2,\ldots,n}(S_{k-1}) = \min_{U_k}\{C_{k,k+1,\ldots,n}(S_{k+1}, U_k)\} =$$

$$= \min_{U_k}\{C_k(S_{k-1}U_k) + C^*_{k+1,\ldots,n}(S_k(S_{k-1}U_k))\}.$$

From here we find $U^*_k(S_{k-1})$.

Having a set of optimal controls, at each stage it is possible to specify an algorithm for influencing the management trajectory in order to keep it in a certain area and at the same time have a minimum of costs

$$C^*_{1,2,..n} = \min_{S_0}\{C^*_{1\ldots n}\}.$$

It should be taken in consideration that coincidence achievement between the feasible and optimal trajectories may be impractical due to high costs.

Let $Y = C_0\prod_{i=1}^{n} X_i^{\alpha_i}$ be the function, that defines the scalar field for the strategy of scientific research control.

Let us find a trajectory leading from the "point" along which *Y* increases the most compared to all other trajectories.

Let us indicate

$$\overrightarrow{du}\{dX_1; dX_2; dX_3\}; \nabla Y\{Y'X_1; Y'X_2; Y'X_3\}.$$

Assuming that $du \uparrow\downarrow \nabla Y$ (collinearity condition), we obtain

$$\frac{dX_1}{Y'X_1} = \frac{dX_2}{Y'X_2} = \frac{dX_3}{YX_3} \Rightarrow \frac{dX_1}{C_{0\alpha_1}X_1^{\alpha_1-1}X_2^{\alpha_2}X_3^{\alpha_3}} = \frac{dX_2}{C_{0\alpha_2}X_1^{\alpha_1}X_2^{\alpha_2-1}X_3^{\alpha_3}} =$$

$$= \frac{dX_3}{C_{0\alpha_3}X_1^{\alpha_1}X_2^{\alpha_2}X_3^{\alpha_3-1}}.$$

From here

$$X_1 dX_1 = \frac{\alpha_1}{\alpha_2} X_3 dX_3;$$

$$X_2 dX_2 = \frac{\alpha_2}{\alpha_3} X_3 dX_3. \qquad (20)$$

Taking into account the natural boundary condition *Y*(0; 0; 0) = 0, we obtain from (20)

$$X_1 = \sqrt{\frac{\alpha_1}{\alpha_3}} X_3; \qquad X_2 = \sqrt{\frac{\alpha_2}{\alpha_3}} X_3.$$

If the time dependence *t* is known, then the equation of the optimal trajectory is practically easily determined:

$$\begin{cases} X_3 = X_3(t); \\ X_1 = \sqrt{\frac{\alpha_1}{\alpha_3}} X_3(t); \\ X_2 = \sqrt{\frac{\alpha_2}{\alpha_3}} X_3(t). \end{cases} \qquad (21)$$

Given the type of digital model, for example

$$Y = 60{,}06 X_1^{0{,}098} X_2^{2.031} X_3^{0{,}198},$$

we obtain for the desired optimal trajectory:

$$X_1 = 70{,}96t; \quad X_2 = 2270{,}7t; \quad X_3 = 709{,}6t. \qquad (22)$$

Next, let $\varphi_1(\Delta X_1, t)$, $\varphi_2(\Delta X_2, t)$, $\varphi_3(\Delta X_3, t)$ be functions of factors. The number of regulation stages, for example, n = 3.

Thus, the system will go through the following states:

$$S_0; S_1(i, j, k); S_2(e, m, p); S_3.$$

The number of stages of management adjustment depends on the manager.

Amendments must be introduced after the results of the previous period's activities become known (Borovik, 2013). It is obvious that the accuracy of approaching the optimal trajectory increases with the growth in the number of regulation stages.

Despite the fact that in the given example the functions $(\Delta X_1, t)$, $\varphi_2(\Delta_2, t)$, $\varphi_3(\Delta X_3)$, are considered known, their knowledge is not generally necessary. It is sufficient to have information on the costs of introduction of factor differentials at each stage of management, which are available in statistical data.

4 RESULTS DISCUSSION

An experienced researcher intuitively grasps the "diameter" of the area of possible variation in the implementation of the management strategy presented in Figure 6. Reasoning in this way, we introduce εi, a value assigned depending on the actual possibilities and which may be different at different

stages. To simplify the calculations, we select two points in each section of the area. We set the "diameter" of the variation area so that $X_1 \in [X_{10} \pm \varepsilon_1 t]$; $X_2 \in [X_{20} \pm \varepsilon_2 t]$; $X_3 \in [X_{30} \pm \varepsilon_3 t.]$

Let us tak ε_i = const, i = 1, 3;

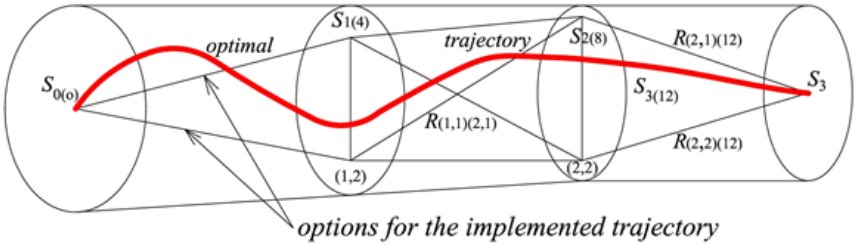

Figure 6: Graphic illustration of optimal management in a domain limited by management quality.

ε_1= 20; ε_2 = 100; ε_3 = 50; $S_0 \equiv S_0(t = 0)$;
$S_1 \equiv S_1(t = 4)$; $S_2 \equiv S_2(t=8)$; $S_3 \equiv S_3(t=12)$;

Let the functions $\varphi_I(\Delta Xi, t)$ $i = \overline{1,..,3}$ be known, determining the costs associated with the achievement of the optimal trajectory. The values φi for all control moments can be found relatively easily, based on the actual conditions that have appeared at a given time.

Thus, for one and management objects ese costs ΔX_i for different periods of management are known and amount to, for example, conventional units:
$C_{1,1}$ = 120; $C_{(1,1)(2,1)}$ =130; $C_{(1,2)(2,1)}$ =180;
$C_{(2,1)(1,2)}$ = 60;
$C_{(1,2)}$ =90; $C_{(1,1)(2,2)}$ = 90; $C_{(1,2)(2,2)}$ =170;
$C_{(2,2)(1,2)}$ = 85.

Then we obtain the "coordinates" of the points of the phase space:

S_1: ⌈ (1, 1): X_1 = 70,96· 4 + 80 = 363,84;
X_2 = 2270,71· 4 + 400 = 9482,82;
⌊ X_3 = 709,61· 4 + 200 = 3038,42;
(1, 2): X_1 = 203,84;
X_2 = 8682,82;
⌊ X_3 = 2638,42;

S_2 : ⌈ (2, 1): X_1 = 727,68;
X_2 = 18965,62;
⌊ X_3 = 6076,83;
(2, 2): X_1 = 407,68;
X_2 = 17365,62;
⌊ X_3 = 5276,82;

S_3: ⌈ (1,2): X_1 = 851,52;
X_2 = 27248,42;
⌊ X_3 = 8515,22;

S_0 : X_1 = X_2 = X_3=0

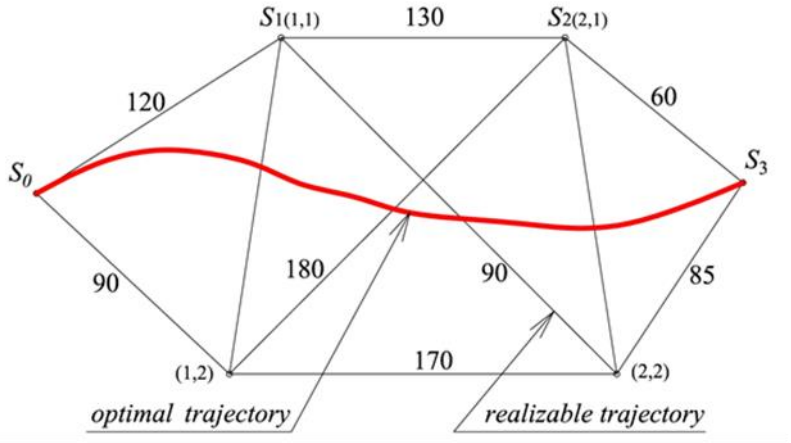

Figure 7: Illustration of the results of strategy trajectory solution for scientific research management.

Using the available data, we obtain for the conditionally lowest costs:

for point (1,1): $C^*_{(1,1)} = 175((1,1) \to (2,2) \to (12))$;

for point (1,2): $C^*_{(1,2)} = 240((1,2) \to (2,1) \to (12))$;

for point *So:* $C_{S_0} = 150 + C^*_{(1,1)} = 120 + 175 = 295.$

Now we will show the trajectory of optimal management according to the chosen strategy:

$S_0 \to (1, 1) \to (2, 2) \to S_3$.

CONCLUSIONS

It was found that, based on a digital model in space and time, it is possible to construct a trajectory of a strategy for research process management, what creates the prerequisites for its automation. The digital model is formed on the basis of a set of data types and transformation rules, what determine the set of rules for its construction and as a subclass of the general class of transformations of basic models. The use of a digital model in space and time, formed from a set of statistical information reflecting retrospective results of studies of the relationship and interdependence of target indicators and factors is shown. Management based on digital models allows for continuous assessment of the accuracy of the desired results. The prerequisite for the accuracy of the model is information redundancy in relation to the model of a single object. The algorithm for the trajectory of the scientific research management strategy was developed. Modeling was carried out using the specified algorithm. Calculations were performed using the suggested model. It was established that it is advisable to consider the trajectory of a management strategy as a certain realizable trajectory of management carried out within the boundaries of the hypersurface region surrounding the trajectory of optimal management.

It was proved that the distance from the optimal management trajectory, which determines the region of acceptable values, is estimated by the quality of management -ρ, which is the aggregate statistical value of the “distance” of the real trajectory from the optimal one. The developed model for the strategy of research process management when a scientific problem is solved, taking into account real conditions based on a digital model, allows for the development of a computer program.

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