Economic and mathematical models for forecasting the development of the space industry

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Abstract

The article examines a problem relevant to the national security of the state, the possibility of applying economic and mathematical models to predict the prospects for the development of the space industry. In modern conditions the, space industry is seen as the basis for innovative development and economic security of the state, which is the driving force of economic development.

After all, in order to sustainably develop the economy and achieve the indicators planned by the government, it is necessary to have a clear idea of the mechanisms and function of the system as a whole and its individual parts.

That is why competent forecasting of the main indicators of the development of the space industry with the identification of key factors influencing it is especially relevant at the present stage. Forecasting of indicators, based on the construction of economic and mathematical models of industry development.

It is determined that the construction of this model begins with the development of a specification of the model, which includes a verbal description of the study, followed by a presentation of the process of its operation in the form of mathematical formulas. It is important to clearly formulate and define the problem, as well as to identify all the factors and patterns that characterize the functioning of the system. Economic and mathematical models can increase the efficiency of the planning system of the industry and increase the accuracy of the process of forecasting its development.

The successful development of the space industry today becomes a necessary condition for preserving national sovereignty both in the military-political aspect and in the field of information security.

Keywords: economic-mathematical model, forecasting, space industry, space activity.

Introduction

The main source of innovation and economic growth in the modern world is science and technology. In recent decades, the space industry has been the engine of research and advanced technology, widely used in other areas of human activity. Nowadays, such common things as weather forecasting, global broadcasting and communication would be impossible without the satellite industry. In modern conditions, humanity is witnessing

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shifts in the technological paradigm both directly in the space industry and in related industries. Examples of this evolution are new phenomena such as space tourism, broadband networking, and private space companies.

Cosmonautics is the main product of world scientific and technological progress, a powerful engine of this progress, continuously providing other sectors of the world economy, with an invaluable and unprecedented flow of new materials, technologies and scientific developments, makes a significant contribution to sustainable development. At the present stage, space activities and its research and production base have already become a naturally functioning branch of the global economy, subject to universal laws and trends (Pajson, 2010).

The space industry occupies a special place among domestic strategic science-intensive industries. It forms the image of the state as a technologically advanced state and shows that the country has a developed intellectual, scientific and technical potential in the space sector, which, must be, effectively used to develop the economy and increase national security.

At the same time, the space sector of the global economy demonstrates dynamic stable development, which is associated with the processes of powerful transfer of space technology from the military to the public, and the development on this basis of a range of commercial services related to space industry and development. All this in general contributes to the commercialization of space activities and the rapid development of space industry, development and sale of space products, technologies and services, which, in turn, gives a powerful impetus to increased industry competition at various levels: global, interregional, interstate and national (Savin, 2018).

Material and methods

The function of forecasting is very important for the development of space assets and systems as elements of the global life support system of society, planning and forecasting can predict the possibility and consequences of all changes.

Forecasting and planning, along with coordination and control, are important elements in the formation of a holistic space management system. Real economic regulation of space development in general, is, expressed, in determining the degree and methods of influence on all subjects of economic relations. It is especially important to be able to reduce (or eliminate) the impact of negative factors on economic processes and stimulate the impact of positive factors. Forecasting itself can help identify such relationships.

Forecasting is one of the forms of indirect state influence on the creation of infrastructure in the space industry. Forecasting is a process of forecast development, the essence of which is to use certain methods to process the available information about the object of forecasting and to form an idea of its evolutionary trends based on the analysis of trends in its development (Bendikov & Hrustalev, 2007).

Among the principles on which the forecasting process is based, we can highlight the following:

- Scientific validity of the forecast (development with the help of scientific methods, taking into account the laws of development of the material world, society and thinking);
- Continuity of forecasting (the forecast must be constantly adjusted to take into account changes in the situation in the country, the world economy);
- A combination of long-term and current forecasting (these types of forecasting are carried out in conjunction, but the priority remains on long-term forecasting);
- Consistency of forecasts (the developed forecast should correlate with related forecasts);
- Multivariate, alternative forecast (it is worth making several forecast options) (Bendikov & Hrustalev, 2007).

Results and discussion

The development of the space industry makes a significant contribution to the processes of globalization of the world economy. In most developed countries, the level of development of the space industry sets important macroeconomic indicators, including influencing the value and growth rate of gross domestic product, determines the competitiveness of the national economy. In turn, the global space market is a large segment of the high-tech market, which is developing quite rapidly. One of the key engines of modern economic progress is innovative technologies in the field of microelectronics, digital and information systems, software, communications and telecommunications, etc.

Most of these developments originate in various areas of the space industry and have a significant impact on various areas of modern life. In general, space activities are an inexhaustible source of innovative technologies in virtually all areas of modern life. At the same time, most industries and services in the world economy are directly dependent on the development of space activities. As a result, space activities are attracting more and more attention not only from states and their associations, but also from large multinational corporations. The expansion of the market and the gradual increase of its participants have an impact on the growth of financial resources in the industry (Nyameshchuk, 2011).

The state's space industry should concentrate modern scientific and technical developments and be a driving force for the growth of the high-tech sector of the economy. Therefore, forecasting the development of the space industry is a relevant and important issue to ensure the sustainable development of the sector, which is able to provide a basis for technological leadership and long-term strategic advantages in a globalized environment.

The space industry is part of the domestic defense-industrial potential and plays an important role in public policy, has a decisive influence on the military and economic security of the state, the military, economic and scientific potential of the country. Space activities are among the most complex types of human activity, and its strong focus on broad international cooperation makes a significant contribution to world processes. Space industry forecasting occupies an important place among other types of space management (Sazonec, 2015).

The interest in the development of the space industry in modern conditions is due primarily to the fact that this industry is part of the defense industry of the country, which affects the defense of the state and its security.

At the present stage, the development of the space industry is, largely determined, by the efficiency of resource provision of enterprises in this industry.

Domestic enterprises of the space industry organize their research and production activities in a dynamically developing market, intensifying competition for access to resources, which requires conceptual scientific and practical solutions in the management of the industry and its structures. The implementation of state policy on the development of the space industry is possible under the condition of sustainable development of research and production activities, which, in turn, is determined, by its resource provision (Degtyarev, 2002).

The main specific features of the space industry are the following:

- The complex nature of the activity, which necessitates the solution of many problems: from research and development to the creation of equipment and its subsequent operation;
- The focus of promising research and development of fundamental purpose on the end result in the form of a science-intensive product;
- Regular updating of fixed assets, development of the experimental base in connection with the need to change technology and maintain a high scientific and technical level of products;
- Significant length of the life cycle of space

industry products, which complicates the process of industry management and increases the responsibility for the selection and implementation of development strategies;

• Intensive innovation and investment process as an important factor in achieving the goals of research and development that accompanies the implementation of projects;

• High degree of uncertainty and the use of forecast estimates of future technologies;

• The key role of the state in the support and development of the space industry (Degtyarev, 2002).

The purpose and main task of the analysis of forecasting objects is the formation of a forecast model. The analysis of the forecast object begins with its description. The description should contain information about the most key indicators, characteristics of the object, the structure of the object and the relationship between the elements of this structure.

Based on the relationship between industry and long-term forecasting and evaluation and qualitative content of forecasting elements, the structure of the forecast of scientific and technological development of the space industry will look like this (Fig. 1).

Modern economic and mathematical analysis of the national space industry is a single set of initial data and the only result is a set of methods for studying the patterns and trends of this activity, methods for studying the prospects of space development and research models for solving problems.

In turn, the methods of analysis of space activities include modern tools of scientific and technical forecasting, including the development of the concept of space activities, methods for determining the needs for space facilities and services, as well as methods for studying the prospects of space industry (Maksimov, 2005).

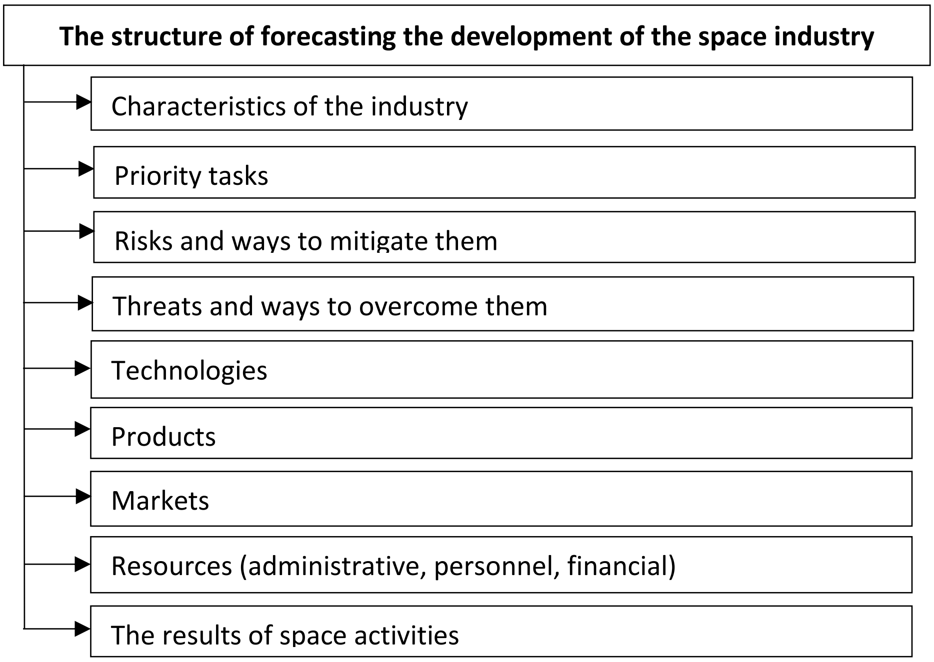

Fig. 1. The structure of forecasting the development of the space industry

Source: (Pajson, 2010).

The study of the prospects for the development of the domestic space industry is based on the use of the model of space potential, from a systemic standpoint, which combines the processes of functioning of the whole set of objects and spacecraft. The development of methods of scientific and technical forecasting, long-term and program macro-design, as well as the study of program implementation processes allows from a single standpoint to organize consideration of all stages of development of the industry.

Characterizing the forecasting of the space industry. It is necessary to note a number of features:

- The production potential of the space industry is a complex hierarchical system, which is characterized by the development of cooperation, both horizontal and vertical links between them – using available capacity, common external and internal resources;
- The development of enterprises in the space industry is, endowed with alternatives. One of the goals of their development is to increase the production capacity of enterprises through organizational and technical measures for technical re-equipment of production of different intensity (Bukhun, 2015).

Different types of models can be used in the development of forecasts for the development of the space industry: optimization, static, (using the time factor), dynamic, factorial, structural, combined and others. The most common methods of mathematical modeling of forecasts for the development of the space industry are the correlation-regression method, the model of Inter-sectoral balance, optimization models.

The essence of the correlation-regression method of modeling the forecast of the space industry is to determine the dependence of the indicator on various factors. To predict the development of the industry using the correlation-regression method, it is necessary to establish the correlation between the predicted indicator and the factors influencing it, determine the form of this relationship, derive a formula (equation) and predict the indicator based on them. The form of communication characterizes the change in the values of one feature from the change of another. It can be linear or nonlinear. The linear form of correlation is, expressed by, the following equations:

$$Y(X) = A+BX \quad (1)$$

$$Y(X) = A+BX+CZ, \quad (2)$$

Where Y (X) is the value of the sign Y at a given value of the factor (X) or factors (X and Z); A, B, C – parameters of the equation; X, Z – values of factors (Fomina, *et al.,* 2014).

The static model of inter-sectoral balance is, designed for, forecasting macroeconomic calculations for the short term (year). In general, it has the following form:

$$S_{aijxj} + Y_i = X_i S_{aijxj} + Y_i = X_{i\,(i=1,\,n),\,(j=1,\,n)}, \quad (3)$$

Where *aij* – coefficients of direct costs (average industry standards of production costs of industry i, used as a means of production to produce a unit of production of industry j); *xj* – production volume j of the consumer industry; *Xi* – gross production of products (services) and industry; *Yi* is the volume of the final product and the manufacturing industry (Fomina *et al.*, 2014).

Models for forecasting the development of the space industry should provide a calculation of the trajectories of this development for the entire forecast period. The state of the space industry in each year should be, characterized by a system of technical, economic indicators and the trajectory of its development – the estimated values of these indicators in the base year and the years of the forecast period. Based on these indicators, an analysis of the development option of the industry, given by its trajectory, and a comparison of different trajectories with each other (Maksimov, 2005). Each trajectory of development reflects an alternative version of the forecast of the development of the industry, which determines the sequence of its state with a certain period of quantization.

In order to develop models for assessing the potential of the space industry, it is necessary to identify the main factors that determine its research and production capabilities and technical and economic indicators, fully characterizing their state and dynamics of development. One of the main such factors is the synchronization of intensity and achieving a balance of production and reproduction processes. The reproducible structure of capital investments should include technical re-equipment, reconstruction or expansion of enterprises in the industry, construction of new facilities at existing enterprises, which is an integral part of technological support for the production of new products in the forecast period.

The system of technical and economic indicators that characterize the forecasting of the development of enterprises in the space industry should include:

- Initial data on their scientific and technical condition;
- Economic standards that meet the requirements of intensive and effective development of enterprises in the industry – the task of reducing production costs;
- Indicators that reflect the goals of development of enterprises in the industry, the order for production, its cost, price, projected sales, profit;
- Data on planned production development projects, introduction of new equipment or technologies, as well as data on possible means of production development in accordance with the expected scientific and technical achievements;
- Data on the volume and sources of funding for the development of space industry enterprises (Fomina *et al.*, 2014).

Models of development of the space industry, reflecting the different strategies of its operation, should contain for each of them the calculation of such a set of technical and economic indicators, which allows for various quantitative and qualitative assessments of alternatives to this development. The methodological basis for such calculation of indicators should be common to all enterprises in the industry methodological principles, rules and recommendations that reflect the specifics of production and planning in the industry, including the system of pricing and financing (Maksimov, 2005; Pajson, 2010).

Each version of the forecast for the development of the space industry should cover a long period (10-15 years) and include various measures to change production capabilities that are strategic for them.

The concepts of products, resources, production processes and circumstances play a key role in the development of tools for forecasting the development of the space industry. These concepts require priority definition in the process of formalization and modeling of innovative development of enterprises in the industry. Suppose there is a finite number of products created by the space industry.

The concept of product used to reflect different products of the same type, with different types of the same product represented as different products. This leads to the fact that the number of products studied in the model will exceed the number of actually existing products, but the final number, of products, will be, preserved.

The set of all products created by the enterprise, which are taken into, account in the development of innovation strategy, is the space of:

$$R_+^I = \{x = x_1,\ x_2, \dots x_I \quad x_i \geq 0, i = \overline{1,\ I}\}$$
$$R_+^I = \{x = x_1,\ x_2, \dots x_I \quad x_i \geq 0, i = \overline{1,\ I}\},$$

All products are, considered, measurable in the appropriate units (Fomina *et al.*, 2014).

The industrial resources used by the enterprises of the space industry represent an element of the space of resources: $x \in R_+^I \in R_+^I$.

The notion of limiting factors that limit the possible values of sets of resources are formalized in the condition

$x \in\in X$, where $x \in\in X$, де $X \subseteq R_+^I \subseteq R_+^I$ -

The set of sets of resources that are available to the enterprise and used as source resources. The boundaries of the resource set X are determined by natural, physical properties and can change over time: *X= X(t)* (Fomina *et al.*, 2014).

Similarly, the products produced at the enterprise (or forecasted before release) products are an element of the product space $y \in R_+^I \in R_+^I$, the positive components of which show the volume of production of the corresponding type. The totality of all sets of products is the production set $Y \subseteq R_+^I \subseteq R_+^I$. The structure and boundaries of the set *Y* depend both on the internal characteristics of the space industry enterprise (resource set *X*, technical and technological capabilities, structural and organizational features, etc.) and on external conditions, primarily market needs. They change over time: *Y= Y(t).*

Accordingly, the production processes for the conversion of raw materials into finished products are determined by a set of technologies available to the enterprise – the technological set *A* = $\{a_1,\ a_{2,}\ \ldots a_m\}$ $\{a_1,\ a_{2,}\ \ldots a_m\}$, each element a_j a_j which is one of the available technological processes and formally defines the mapping: a_j a_j : *X* $\rightarrow\rightarrow$ *Y*.

Like the resource set X and the production set Y, the technological set A is not stationary, but time variable *A= A(t)*, not only in composition but also in the number of its elements.

Any of the, technologies, can be used with different intensity or not used at all. The choice of a set of source resources, a list of technologies used, the, intensity of their use, range and volume of finished products are the content of the management decision *u (t),* which determines the production activities of the space industry. The metaset *W(t)* = $\langle X(t), Y(t), A(t)\rangle$ $\langle X(t), Y(t), A(t)\rangle$ is the identification module of the general model of development of the space industry enterprise, and the element *w(t)* = $\langle x(t), y(t), a(t)\rangle$ $\langle x(t), y(t), a(t)\rangle$ specifies its current state (Maksimov, 2005; Pajson, 2010).

According to the applied management decisions *u (t)* the dynamic forecast model of development of the enterprise of space branch defines finite or infinite sequence of its possible states $\{\langle x(t), y(t), a(t)\rangle\}_{t=0}^{T}$ $\{\langle x(t), y(t), a(t)\rangle\}_{t=0}^{T}$ or $\{\langle x(t), y(t), a(t)\rangle\}_{t=0}^{\infty}$ $\{\langle x(t), y(t), a(t)\rangle\}_{t=0}^{\infty}$, which can be determined using systems theory as trajectories of its development (Makarenko, 2006; Maksimov, 2005).

The profit of the space industry at time t is a function of the parameters that characterize its internal state and external circumstances: *f(t) = f(w(t), q(t))*. Analyzing the development of the enterprise it is necessary not only to explore the possibility of making a profit at any time, but also the prospects for its receipt in the future. To do this, perform an analysis and forecast of the most appropriate trajectories of development of enterprises in the industry.

Given the peculiarities of the study of the processes of sustainable functioning and progressive development of the domestic space industry, forecasting needs to, be carried out, on, the basis of the cognitive models (Makarova et al., 2015). According to the general theory, cognitive analysis and modeling of space industry development consists of the following elements:

1. Cognitive structuring – at this stage the cognitive structuring of information about the functioning of the space industry and trends in its development (foreign and domestic policy, socio-economic, etc.), which affect the efficiency of scientific and industrial activities of the space industry. This stage consists of collecting, analyzing and synthesizing information and developing a cognitive map that conceptually reveals the conditions and mechanisms of the space industry.

The structuring of information is, performed, in order to create a set of basic factors: X = $\{x_1,\ x_2, \ldots, x_n\}$$\{x_1,\ x_2, \ldots, x_n\}$and identify cause-and-effect relationships between them.

For each basic factor, its 'trend' is located and calculated – the rate of change of the indicator that characterizes the object that is associated with a particular factor. For the identified causal relationships between the underlying factors, the nature (negative or positive) and strength of these relationships are determined. The values of variables are measured on a linguistic scale and determined by a number from the interval [-1, +1].

The development of a cognitive map formally consists in constructing an oriented graph: G (X, A), where X is the set of vertices corresponding to the set of basic factors; A – many arcs showing the interaction of factors (Makarova et al., 2015).

At this stage, subsets of control and target factors, as well as the vector of initial trends of basic factors are, distinguished from the, set of basic factors. Managers are, selected from a number of factors related to the external environment or the control object that may be affected by the control object. Targets are, selected from factors that characterize the state and objectives of the object of management.

2. Structural analysis of the cognitive map. Effective management of a problem situation requires the study of its structural features, i.e. detailed characteristics of causal relationships between the underlying factors. A comprehensive analysis of the map, designed to study such properties is to assess the objectives of management for consistency and consistency, the effectiveness of the total impact of control factors on the target.

3. Scenario modeling of the situation is to be, carried out in the modes of management development and self-development.

4. Evaluation of simulation results. To determine the degree of effectiveness of management decisions, a system of indicators is, proposed, that assess the degree of achievement of the goal – the coefficient of goal achievement.

5. Cognitive monitoring of the situation, which allows in case of change of the situation to perform modification of the cognitive map and to conduct additional analysis and modeling of the situation (Makarova et al., 2015).

The methodology of forecasting and analysis of the space industry as a whole allows us to take into account the requirements of new conditions.

However, for more complete and detailed research it is necessary to improve the methodology in the direction of expanding the number of factors, assessing the final results of service delivery, building a system of indicators to measure the degree of program implementation, strategic goals, tactical objectives and quantification of budget expenditures.

Conclusions

The space industry provides the state with the opportunity to provide a qualitatively new level of solving defense and strategic tasks of international cooperation, stabilization of the domestic economy, strengthening its position on the world stage.

Prospects for the development of the space industry, are related to:

• Meeting the growing needs of government agencies, regions and the population in space and services.

• Ensuring compliance with the world level of spacecraft

• Development of international integration in solving vital problems of expansion of international cooperation.

• Expanding and improving the efficiency of the use of outer space in various sectors of activity to address the challenges facing the state.

The space industry is an important component of sustainable socio-economic development and a guarantee of national security. The availability of its own rocket and space assets significantly contributes to the implementation of a balanced state policy in accordance with the adopted strategies, concepts and programs in the political, economic, social, military, scientific and technological, information and other areas.

The main problems of development of enterprises in the space industry include:

• Insufficient funding of the industry;

• Lack of effective state policy and legislative support;

• Insufficient domestic demand for the results of the space industry;

• Aging of fixed assets and material and technical base;

• Lack of qualified personnel;

• Weak professional management.

Appropriate tools for economic and

mathematical modeling of forecast technical and economic indicators of space industry development allow us to form alternative options for industry development, and choose the best ones.

Creation of flexible, individually adapted models, on the basis, of the special economic and mathematical device helps to reduce an error during forecasting. This significantly increases the efficiency of forecasting and analysis systems used by space companies.

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