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Modeling knowledge generation processes in a digital economy conditions

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***Abstract* — The research of the processes of knowledge generation in high-tech industries by means of the use of an institutional approach for modeling the system for the formation of new knowledge is an important task for increasing the efficiency of innovative development of economic entities. The article is devoted to the development of a new economic concept - the resource potential of knowledge generation and empirical testing of its applicability for high-tech production of complex products in the digital economy. The methodological basis of the research is based on the theoretical concepts of strategic management, institutional economic theory. A theoretical analysis of study approaches of factors increasing the use of various types of resources in high-tech enterprises has been carried out. The authors have developed a methodology for assessing the generation of knowledge in the innovation activities of instrument-making enterprises of the military-industrial complex based on the use of functional analysis, which made it possible to establish relationships and dependencies between the resources of an enterprise and the product life cycle. The authors have proposed a schematic image and a formalized filling of the theoretical potential of using the resources for the generation of knowledge of a manufacturing enterprise, which allows to evaluate the capabilities of an enterprise in the implementation of intellectual activity. As a result of the empirical research conducted by the authors at a large Russian enterprise of the military-industrial complex, the actual distribution of resources at each of the seven stages of the life cycle of a complex product was revealed. Comparison of the theoretical and actual potentials of the application of knowledge generation resources allowed us to determine the direction of optimizing the use of resources for the most effective introduction of new products. The research results have an applied nature and can serve as a basis of a strategy for the development of industrial enterprises.**

Keywords — resource potential, knowledge generation, high-tech production, economic institutions, digital economy.

I. INTRODUCTION

The rapid development of economic activity has led to a contradiction between traditional types of economic activity and new processes occurring in society. The contradiction between these types of activities is in different speeds of business and in various business tools accordingly. The introduction of digital technology, mobile communications and the Internet have changed the impact of the driving forces of social development on economic activity. If we refer to the driving forces of society innovators, the possession of new technologies stimulates the formation of a new landscape of economic activity.

The application of digital technologies acquires particular relevance in the formation of new knowledge for high-tech industries. In this case, it is possible to use an institutional approach for modeling a system for generating new knowledge. At the same time, there is no research in the domestic and world economic literature devoted to the institutional description of the generation of knowledge for high-tech productions of complex products.

The purpose of this study is to develop a new economic concept - the resource potential of knowledge generation and empirical testing of its applicability for high-tech production of complex products in the digital economy.

II. RESEARCH METHODOLOGY

The regulatory function of institutions implies that a certain order or relative stability can be achieved with all the diversity and differences at the microeconomic level. The existence of institutions suggests that rules, restrictions, customs, and ideas can, through certain psychological and social mechanisms, change individual goals and preferences in a certain way. This change can increase the likelihood and contribute to the stability of institutions.

According to A.M. Sergeyev, the methodological features of neoinstitutional theory compared with neoclassical theory consist in the principle of methodological individualism is more consistently implemented by neoinstitutionalists. According to this principle, all collective communities are subject to explanation from the point of view of the purposeful behavior of the individual agents making them [Sergeev, 2005]. In addition to the resource and technological constraints characteristic of neoclassical models of rational choice, a new class of constraints is introduced, due to institutional factors. The behavioral prerequisites of analysis are radically modified by introducing the principles of limited rationality and economic opportunism [Avtonomov, 2006].

Thus, at the present stage of development of institutional economic theory, three-level schemes are the most demanded research methods of various systems that carry out economic activities [Shastitko, 2002]. Within the framework of this three-level scheme, the first level is represented by a person who is considered according to the postulates of neoclassical economic theory, a contractual person in institutional economic theory. The various institutional arrangements are the second level, and the third one is the institutional environment.

D. Norte's methodological approach, which is the basis for the institutional description of economic systems, is based on the following key points [Ananyin, Odintsova, 2000]:

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1. Having personal interests and strictly follow personal goals is a strategy of behavior only for individuals;
2. interactions between individuals are always carried out within the boundaries of sets of institutions, both formal and informal, affecting these interactions;
3. All interactions of individuals in various extraordinary situations result in the emergence of new formal and informal institutional changes.

In other words, an individual, on the one hand, is limited in their actions by the institutional structure that exists at a given point in time; on the other hand, they can make changes to this structure in accordance with their various preferences.

Consequently, the center for describing various economic systems with the help of the apparatus of institutional economic theory is the idea of the evolutionary nature of the development of all institutional structures and environments. With this approach, the institutional economic theory of our day has a lot of points of contact with evolutionary theory and, as a result, they can be considered as a single institutional and evolutionary economic theory.

In accordance with the Order of the Government of the Russian Federation, “Digital economy is an economic activity, the key factor in which production is digital data, and contributes to the formation of the information space taking into account the needs of citizens and society in obtaining high-quality and reliable information and the application of Russian information and telecommunication technologies, as well as the formation of a new technological basis for social and economic sphere".

As a part of the program to create conditions for the country's transition to the digital economy, the digital economy itself includes five areas that create institutional and infrastructural conditions, as well as contribute to the elimination of various kinds of restrictions for the creation and development of high-tech business: personnel and education, information infrastructure, information security, the formation of research competencies and technological reserves, regulatory regulation.

Let's note that the interrelation of globalization of market activity, new models of market trade and the increase in competitiveness of virtual worlds in cyberspace caused by the introduction of advanced digital technologies [DeSousa, McConatha, Lynch, 2011]. The influence of robots and artificial intelligence leads to a significant increase in labor productivity in the business environment and the economy as a whole [Dirican, 2015]. The digital "leverage" provides an analytical technology for e-government to support social investment, which is fully consistent with the concept of pushing the theory of behavioral economics [Gregor, Lee-Archer, 2016].

It was the introduction of digital technologies that ensured the choice of various strategies for the development of objects of economic activity at various levels in the context of using models of multi-parameter decision-making [Hsu, Tsai, Tzeng, 2018]. In this case, there is a need for valuation of the means of applying digital technologies [Volkmann, Westkamper, 2013].

Thus, the essence of the digital economy is the use of advanced digital technologies to conduct business.

Modern digital society is changing the types of social networks and, as a result, new relationships are established in the form of institutional infrastructure [Fletcher et al, 2016]. Digital society poses the problem of agreements between agents, their agreement to interact in the existing conditions [Faith, Prieto-Martin, 2016].

Consequently, a digital society, in which the main elements are accepted rules and restrictions, can best be described within the framework of institutional economic theory. At the same time, institutional description acts as an alternative method of modeling economic activity, reflecting the heterogeneous nature of modern economic theory [Nekipelov, 2017].

In relation to a high-tech enterprise, we consider the institutional support of the product life cycle of this enterprise.

The product life cycle in manufacturing plants may include the following phases (steps): 1) research and marketing, 2) developing technical specifications and modeling, 3) design and software development, 4) design documentation development, 5) technological documentation development, 6) product manufacturing, 7) product testing [Popov, Vlasov, Shishkin, 2014].

Resource planning occurs in two stages: at the stage of marketing research and market analysis, as well as at the stage of development of design and technological documentation.

At the stage of market analysis, after the receipt of an order for a manufacturing enterprise, researches are carried out. The company organizes interaction with the head structure with the help of various contests and tenders, as well as with business structures with the help of various contests and tenders, or carries out marketing research on its own. As a result, in the form of technical proposals and technical assignments, tender documentation is developed, containing information on the necessary resources for the development of research documentation, modeling, development of software and information support. In other words, material, human, informational and financial resources are initially determined for the implementation of the first five stages of the product life cycle. In the process of conducting research, an enterprise, as a rule, organizes interaction with higher educational institutions, research organizations and creates joint laboratories, forms educational research complexes, and develops departmental activities on its basis.

At the stage of development of design and technological documentation, the technological processes of production and product testing are developed in detail, an analysis of the market of necessary materials and components is being carried out, technological tasks for developing software and information support for production processes are being created, the number of employees is being planned, cost estimates are being formed. I.e. all kinds of resources are planned for the stages of production and testing.

When resources are planned, knowledge generation institutions are formed in accordance with the stages of the product life cycle. Institutes of knowledge generation, as well as the results of intellectual activity are shown in Table 1.

The table below shows that each stage of the product life cycle corresponds to certain institutions of knowledge generation, in which the results of the inventive activity are formed.

TABLE 1. INSTITUTIONAL SUPPORT OF THE VARIOUS STAGES OF THE PRODUCT LIFE CYCLE

Stage of the product life cycle	Relevant knowledge generation institutions	Intellectual performance
1. Research, marketing	- Institute for Market Analysis. - Institute of Primary	1. Know-how; 2. Patents; 3. Publications;

	Market Research for Purchased Components and Materials	4. Scientific reports; 5.Marketing reports; 6. Competitive documentation; 7. Patent research.
2. Technical assignment, research documentation, modeling	- Institute of Development Management. - Institute of Marketing Management.	1. Sketch design; 2. Technical proposals; 3. Scientific and technical report; 4. Inventions; 5. Publications; 6. Outrunning enterprise standards.
3. Development of electrical circuits, software	- Institute of circuit design and programming.	1. Technical Report; 2. Methods; 3. Private technical specifications; 4. Publications; 5. Inventions; 6. Computer programs.
4. Development and documentation of design solutions 5. Development and documentation of technological solutions.	- Institute of design and technological preparation of production. - Institute for the purchase of components and materials	1. Technical reports; 2. Standards of enterprise; 3. Technical conditions; 4. Technological processes; 5. Inventions.
6. Manufacturing	- Institute of production. - Institute of Technical Control	1. Industrial samples; 2.Programs for industrial equipment.
7.Product testing	- Institute of Quality Management	Test reports

Introduction of the resource potential of knowledge generation

Schematically, the potential of using knowledge generation resources, by analogy with the market potential of enterprises [Popov, 2002], can be shown as a cube (Fig. 1).

By the resource potential of knowledge generation, we will mean the many of the enterprise's facilities and capabilities for using information, labor, material and financial resources in knowledge generation activities and their implementation in innovation processes.

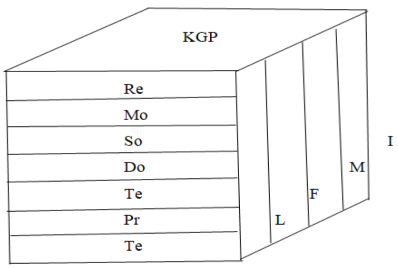

Fig. 1 Schematic representation of the resource potential of knowledge generation KGP (Knowledge Generation Potential).

Here: Re - research; Mo - modeling; So - software; Do - development of documentation; Te - technological support; Pr - manufacture of the product; Te - product testing; L - labor resources; F - financial resources; M - material resources; I - information resources.

The resource potential of knowledge generation at the n-th stage of the product life cycle can be calculated using the formula of additive terms with weights:

$$P_n=k_1K_n+k_2L_n+k_3M_n+k_4I_n, \quad (1)$$

where K_n is financial resources at the n-th stage of knowledge generation; L_n is labor resources at the n-th stage; M_n is material resources at the n-th stage; $I_n$is information resources at the n-th stage.

The assessment of the weights of the terms in relation (1) was carried out by expert survey methods. As a result, the following results were obtained.

Stage 1. Research, marketing

After receiving the order, at the first stage of research and marketing, the share of human resources is significantly increased. This is due to the need to develop a general plan for creating a product. As a result, there is a need for highly qualified personnel in various fields of science. However, also at the first stage, the share of information resources is high, since conducting research requires special knowledge, and the necessary software is required for carrying out calculations. On the other hand, the share of financial and material resources is significantly lower, which is explained by the absence of any production and technical processes and the low need to provide jobs with expensive equipment. Based on this, the potential for applying the knowledge generation resources at the first stage is as follows:

$$P_1=0,15K_1+0,5L_1+0,05M_1+0,3I_1 \quad (2)$$

Stage 2 Technical assignment, research documentation, modeling

Human resources remain the main point at the stage of creating the technical specifications, the design of research documentation and modeling. The reason is the same - the need for highly qualified personnel capable of solving super-complex tasks. As for information resources, they are lower than at the first stage due to the fact that the work performed is based on information and knowledge gained earlier, but additional software is needed here. Financial resources have the same share as information, but are slightly higher than the previous stage, due to the additional funding of software. The share of material resources is gradually increasing due to the provision of jobs. Consequently, the potential of using knowledge generation resources at the second stage consists of the following components:

$$P_2=0,2K_2+0,5L_2+0,1M_2+0,2I_2 \quad (3)$$

Stage 3. Development of electrical circuits, software

At the development stage of electrical circuits and software, the largest role is still assigned to human resources, although their share has decreased in favor of information resources as compared to the previous stage. This can be explained by the growing need for software, the need to create databases. The potential use of knowledge generation resources in the third stage is as follows:

$$P_3=0,2K_3+0,4L_3+0,1M_3+0,3I_3 \quad (4)$$

Stages 4 and 5. Development and documentation of design and technological solutions

At these stages, namely at stages 4 and 5, the development and documentation of design and technological solutions is carried out. There is a large proportion of human and information resources, because this is where highly qualified specialists create methods, computer programs, standards, technological conditions, and describe technological processes. The share of material and financial resources is not so significant, since the material base does not yet require significant financial investments. In this regard, the potential use of knowledge generation resources in the fourth and fifth stages can be described respectively as follows:

$$P_4=0,15K_4+0,4L_4+0,1M_4+0,35I_4 \quad (5)$$

$$P_5=0,15K_5+0,4L_5+0,05M_5+0,4I_5 \quad (6)$$

Stage 6. Product manufacturing

The product manufacturing stage requires the purchase of new equipment, technological lines, new production modules are being created here, new modules are being mastered. This explains the large share of material resources, as well as an increase in the share of financial resources. At this stage, human resources are of great importance, although their value is lower than the previous one. This is due to the organization of the production process, technology debugging. The share of information resources is declining, which is due to the lack of research and development, although there are still processes for improving software for equipment. The potential of using knowledge generation resources at the sixth stage can be represented as follows:

$$P_6=0,25K_6+0,25L_6+0,4M_6+0,1I_6 \quad (7)$$

Stage 7. Product testing

Significant financial resources are required at the stage of testing the finished product. This is due to the creation of conditions for the organization of system settings and quality control of the product. That explains the high proportion of material resources. The potential of using knowledge generation resources at the seventh stage is as follows:

$$P_7=0,4K_7+0,15L_7+0,25M_7+0,2I_7 \quad (8)$$

Empirical research procedure

For an empirical study of the applicability of the author's concept of the resource potential of knowledge generation, we used the data of high-tech production of complex products in the digital economy at one of the large Ural enterprises.

The actual data on the use of resources at each stage of the life cycle of the production of complex products was obtained from different departments of the enterprise responsible for the specific stages of the life cycle of production of products.

To assess the financial resources the accrued wages were determined. The share of workers responsible for the implementation of each stage of the life cycle of a complex product is the share of labor resources at this stage. Material resources were determined on the basis of the cost component of the technical re-equipment plan. The share of information resources was estimated by the share of information and computer support at each stage of the product life cycle.

III. Results of the Research

As a result of the study, we obtained the following distribution of resources across the stages of the product life cycle (Table 2)

TABLE 2. EMPIRICAL VALUES OF ELEMENTS OF POTENTIAL USE OF KNOWLEDGE GENERATION RESOURCES (%)

Life stages	Resource allocation				
	Labor	**Financial**	**Material**	**Information**	**Total**
Study, marketing	24	23	15	38	100
Modeling	23	26	11	40	100
Software	20	16	32	32	100
Construction	21	21	5	53	100
Technology development	30	31	9	30	100
Product manufacturing	28	31	27	14	100
Product testing	28	27	22	23	100

Comparison of empirical data and weights of the theoretical potential for the use of resources show significant discrepancies between the actual and theoretical values of the share of the resources used at each stage of the product life cycle.

For example, we see the following results at the stage of conducting research and marketing analysis (Fig. 2).

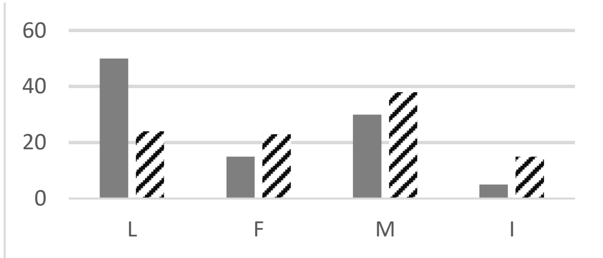

Fig. 2. The distribution of knowledge generation resources at the stage of research and marketing analysis - potential (left, gray bar) and actual (right, shaded bar) in %.

Here and further: L - labor resources, F - financial resources, M - material resources, I - information resources.

We see a significant redistribution of resources in the direction of increasing the share of information and financial resources.

At the second stage of the product life cycle - the stage of preparation of the technical specification, research documentation and modeling, the following results were obtained (Fig. 3).

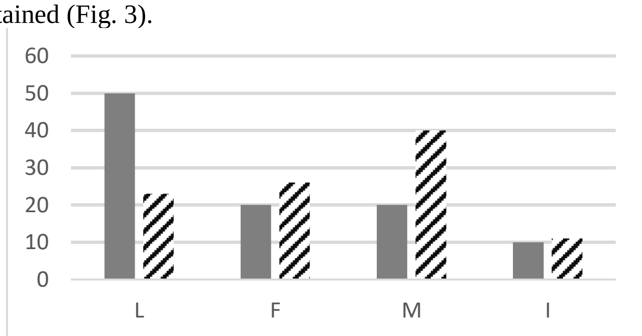

Fig. 3. The distribution of knowledge generation resources at the stage of drawing up technical specifications, research documentation and modeling - potential (left, gray bar) and actual (right, hatched bar) in %.

The share of material and labor resources increases noticeably at this stage.

When analyzing the third stage of the product life cycle - the stage of developing electrical and software circuits, the following results were obtained (Fig. 4).

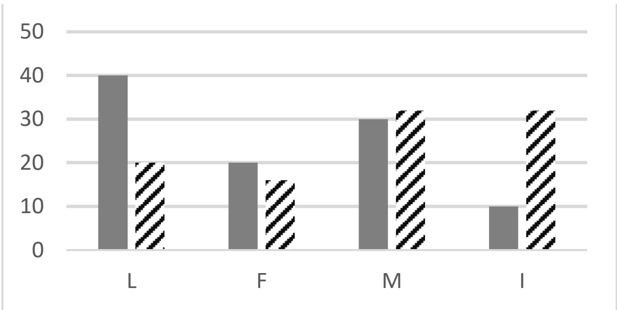

Fig. 4. The distribution of knowledge generation resources at the design stage of electrical and software schemes - potential (left, gray bar) and actual (right, shaded bar) in %.

Here we see a redistribution of resources towards material and informational.

During the studies of the fourth stage of the product life cycle - the stage of development of design documentation, the following results were obtained (Fig. 5).

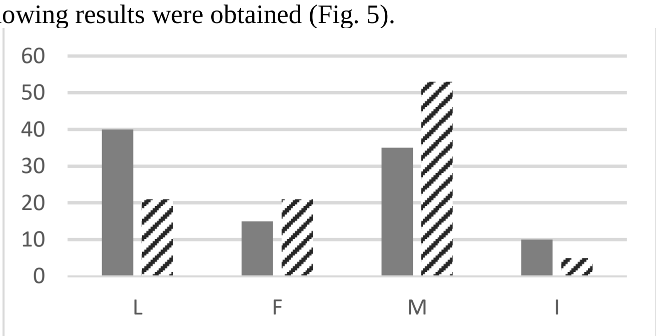

Fig. 5. The distribution of knowledge generation resources at the stage of development of design documentation - potential (left, gray bar) and actual (right, shaded bar) in%.

Figure 5 shows the redistribution of resources to the material ones.

When analyzing the fifth stage of the product life cycle - the stage of development of technological documentation, the following results were obtained (Fig. 6).

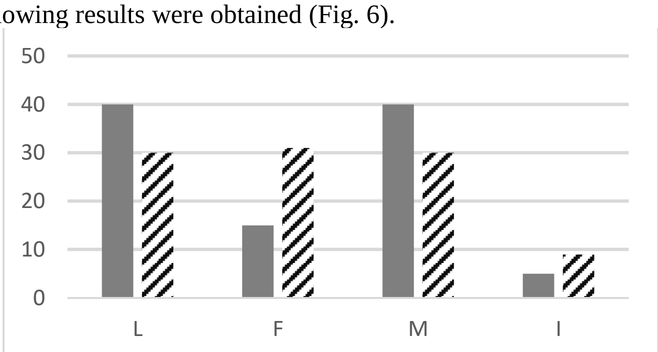

Fig. 6. The distribution of knowledge generation resources at the stage of development of design documentation - potential (left, gray bar) and actual (right, shaded bar) in%.

Here resources are redistributed in the direction of increasing the share of material and human resources.

At the sixth stage of the product life cycle - the product manufacturing stage, the following results were obtained (Fig. 7).

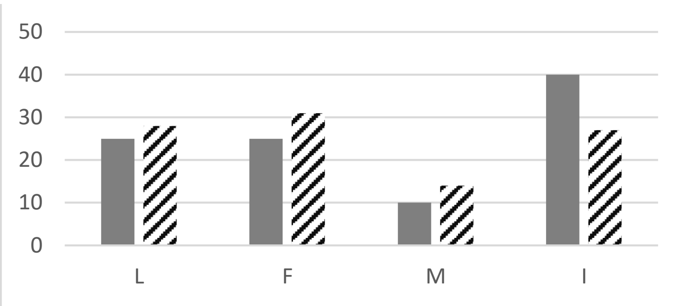

Fig. 7. The distribution of knowledge generation resources at the stage of manufacturing a product - potential (left, gray bar) and actual (right, hatched bar) in %.

At this stage, the share of human and financial resources increases significantly.

When analyzing the seventh stage of the product life cycle — the stage of product testing, the following results were obtained (Fig. 8).

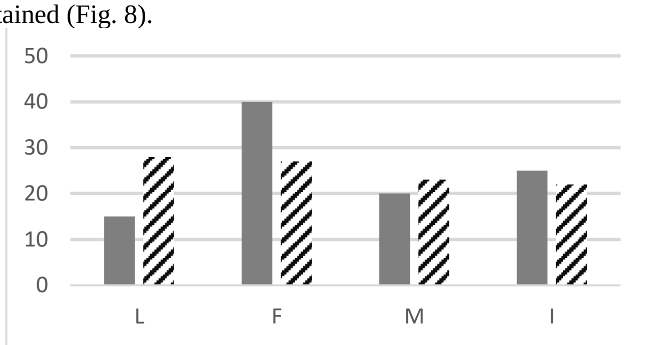

Fig. 8. The distribution of knowledge generation resources at the stage of product testing - potential (left, gray bar) and actual (right, hatched bar) in %.

Figure 8 shows the redistribution of resources towards financial ones.

IV. Discussion of Results

The analysis of empirical data allows to formulate directions for optimizing the use of resources at each stage of the product life cycle.

At the first stage of the life cycle during research and marketing analysis, it seems appropriate to analyze the use of labor and material resources in the direction of reducing them. The authors believe that it may be more preferable to assess the distribution of the shares of the above resources, carried out previously by experts. In other words, it is possible to implement the solution of problems of marketing analysis and research of a product at its first stage of the life cycle can be carried out by a smaller number of personnel while simultaneously using less equipment.

At the second stage, the development of technical specifications and research documentation requires a significant reduction in the share of material resources, possibly due to an increase in the number of employees or an improvement in the quality of staff.

During the third stage - the development of electrical circuits, software, it is necessary to reduce the share of information resources, again by increasing the number of personnel and improving the quality of work with personnel.

At the fourth stage of the product life cycle - the development of design documentation to increase the effectiveness of knowledge generation will help a significant reduction in the share of material resources.

At the fifth stage, in the development of technological documentation it is advisable to reduce the share of financial and information resources.

At the sixth stage of the life cycle, in the manufacture of a product, a slight decrease in human, financial and material resources due to an increase in the share of information resources will lead to the optimization of knowledge generation processes.

Analysis of the allocation of resources at the seventh stage - when testing the product - shows the need to reduce the share of human resources with a possible increase in financial resources.

V. CONCLUSIONS

The following theoretical and practical results are obtained at the research in order to develop a new economic concept - the resource potential of knowledge generation and empirical testing of its applicability for high-tech production of complex products in a digital economy.

Firstly, it is shown that the resource potential of knowledge generation is a combination of the enterprise's facilities and capabilities in using information, labor, material and financial resources in knowledge generation activities and their implementation in innovative processes. The resource potential of knowledge generation is part of the resource potential of the enterprise, reflecting the main elements of the innovation process, allowed to obtain the following theoretical and practical results.

Secondly, a correspondence has been established between the life cycle of a product and the institutional support of intellectual activity in the generation of knowledge in a modern production enterprise.

Thirdly, a schematic depiction and formalized filling of the theoretical potential of using the knowledge generation resources of a manufacturing enterprise, allowing to evaluate the capabilities of the enterprise in the implementation of intellectual activity, is proposed.

Fourthly, as a result of the empirical research carried out by the authors at a large Russian enterprise of the defense-industrial complex, the actual distribution of resources at each of the seven stages of the life cycle of a complex product was revealed.

Comparison of the theoretical and actual potentials of the application of knowledge generation resources allowed us to determine the direction of optimizing the use of resources for the most effective introduction of new products.

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