

Adaptation of high-tech knowledge-intensive enterprises to the challenges of industry 4.0

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Abstract. In order to succeed in a competitive environment, enterprises and organizations must quickly respond to external influences, such as digitalization, expansion of information exchange, and challenges caused by Industry 4.0. High-tech knowledge-intensive enterprises that develop and commercialize their original innovative products and technologies as well as provide intellectual services in the field of high technologies are the first to respond to such challenges. A number of works on how the digitalization in economy impacts organizational and managerial activities of enterprises, their R&D, and creation, production and commercialization of innovative products are analyzed. As the results of the study, a number of properties and patterns that determine the successful adaptation of innovative enterprises to the challenges of Industry 4.0 were identified. Among them there are material resources, including technology and equipment, scientific and technological achievements, financial, personnel and information support and adaptive organizational and economic capabilities. It is shown that in order to adapt to the challenges of Industry 4.0, enterprises must match capabilities of the digital economy with their material, intellectual and production resources using innovative potential as a measurement tool. It is determined that the procedures for assessing the innovative potential of enterprises can become an effective tool for assessing both quantitative/qualitative indicators of enterprises and degree of their adaptation to the challenges of Industry 4.0. The proposed methodology for a comprehensive assessment of industrial enterprises' innovative potential as the degree of their adaptation to the challenges of Industry 4.0 was implemented at the high-tech knowledge-intensive enterprises "Shtorm" and "Tekhnotron". Both of them are well known for their innovative developments in the field of welding production. It was demonstrated that the proposed methodology allows not just assessing the degree of adaptation to the digital economy and the challenges of Industry 4.0, but also assessing the impact of planned activities on innovations and determine methods and means of responding to the changes in external and internal environment of enterprises.

1 Introduction

In work [14], it was convincingly shown that the implementation of the concept of the

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fourth industrial revolution is possible only within the framework of a global multifactor organizational and technical system that ensures both production of products and their commercial implementation. At the same time, a number of authors [5, 11] note consumer requests for complex knowledge-intensive products. The constantly growing commodity market of such products increases the requirements for the uniqueness of knowledge-intensive developments, technological sophistication and product improvement. It is well known [17] that a significant role in increasing the share of complex knowledge-intensive products is played by high-tech knowledge-intensive enterprises that develop and commercialize their original innovative goods, products and technologies, and provide intellectual services in the field of high technologies. It is noted [1] that the success of such enterprises is due to the full use of the opportunities and advantages that advanced digital technologies provide. Their development provided the ability to exchange data in production technologies, including cyber-physical systems, the Internet of things, big data and analytics, augmented reality, additive manufacturing, modeling, horizontal and vertical system integration, autonomous robots, and cloud computing. In this way, digital technologies help integrate and combine intelligent knowledge-intensive equipment and personnel to build systematic value chains and innovative products [26]. For this entire set of qualitatively new production relations and the conditions for managing the value chain throughout the entire life cycle of innovative products, the name Industry 4.0 has been fixed.

Of course, all enterprises that are striving to achieve competitive advantages must find adequate answers to the challenges of Industry 4.0. However, in our opinion, so far insufficient attention has been paid to practical issues of adapting the activities of high-tech knowledge-intensive enterprises to the challenges of Industry 4.0, assessing the achieved level of their adaptation. Therefore, the aim of the work is to consider the main aspects that determine the possibility of successfully adapting the activities of high-tech knowledge-intensive enterprises to the challenges of Industry 4.0.

2 Materials and Method

The research material was statistical data on the innovative activities of Russian enterprises, the works of a number of domestic and foreign scientists, regulatory documents, as well as own scientific, theoretical and practical studies.

Analytical methods of comparative analysis and data generalization were used as a tool, which made it possible to identify areas that need further study, including the indicators of success of innovative activities and staff motivation. Synthesis and induction were applied in the formation of conclusions. The use of these methods allowed us to better understand exactly how high-tech knowledge-intensive enterprises should adapt to the challenges of Industry 4.0. It is proposed to assess the degree of adaptability to changes in the external environment based on characteristic changes in the indicators of innovative potential of enterprises over a certain period of time. The calculation of the dynamics of changes in the values of the indicators made it possible to conduct a comparative analysis and develop recommendations for adapting to the challenges of Industry 4.0 of a number of high-tech knowledge-intensive enterprises.

3 Results

It is well known that the success of high-tech knowledge-intensive enterprises is influenced by their external and internal environment. Knowledge of the state and dynamics of environmental changes allows us to justify the necessary management decisions both to

level its negative impact and to strengthen positive trends. Both the external and internal environment are characterized by a number of factors. Traditionally, for example, the authors of [23] distinguish economic, political, market, social, environmental, legal, and international factors in the external environment. A significant role is also played by such factors as consumers, suppliers, competitors and contact audiences, the capacity of the labor market, and the ability to train the necessary specialists. Internal environment factors should be divided according to the level of influence, effectiveness, level of regulation, nature of consequences, possible risks, frequency and environment of impact.

It should be noted that the internal environment of any enterprise is in contact with the external in order to obtain the data necessary for successful operation. In this regard, the digital transformation of the internal environment will undoubtedly provide the enterprise with competitive advantages. At the same time, the digital transformation of enterprises should be understood as digitalization with a phased integration of digital technologies, processes and competencies. The author of [19] states that only the digital transformation of enterprises can ensure their successful adaptation to the realities of Industry 4.0. The author of [8] also notes that the successful adaptation of high-tech knowledge-intensive enterprises to environmental challenges, including the conceptual features of Industry 4.0, should be due to the full use of advanced digital technologies.

In this regard, we will consider how digital technologies affect the success of enterprises. Obviously, the use of digital technologies requires the digitalization of all stages of enterprise activity, the availability of modern computer technology and software, qualified users. This refers to the creation and commercialization of innovative products using integrated information and communication digital technologies. Examples of integrated services include PLM-systems (Product Lifecycle Management) and BPM-systems (Business Process Management). The specifics of these systems include the ability to integrate automation systems of various vendors, as well as various automated control systems of many manufacturing companies. This allows, as noted in [22], to ensure uninterrupted operation of ERP, CAD, PDM, CRM, SCM systems, and a number of other specialized automation and control systems.

Therefore, digital technologies modify organizational and managerial activities, significantly increasing its effectiveness and quality. They will allow you to plan and control, as well as coordinate and integrate processes, make timely adjustments to the course of activities, provide quick access to any information, support decision-making at different levels of management, facilitate the organization of high-quality communications within the enterprise, support management accounting, marketing, finance, resource management. This is also facilitated by such information technologies as cloud computing and data storage, big data and advanced analytics.

The generalized effect of digitalization tools on the management efficiency of high-tech knowledge-intensive enterprises is shown in Fig. 1.

In addition to the general increase in the effectiveness of management activities, digital technologies can significantly facilitate, accelerate and reduce the cost of R&D, which occupy a significant place in the innovative activities of high-tech knowledge-intensive enterprises. This can be achieved both through the introduction of CALS-technologies and computer-aided design systems such as CAD/CAM/CAE, with multidimensional modeling of complex products, using proven mechanisms for assessing potential risks that arise at all characteristic stages of the implementation of any promising idea. In addition, both the stage of creation and testing of an innovative product prototype can be significantly reduced through the use of augmented production and virtual reality.

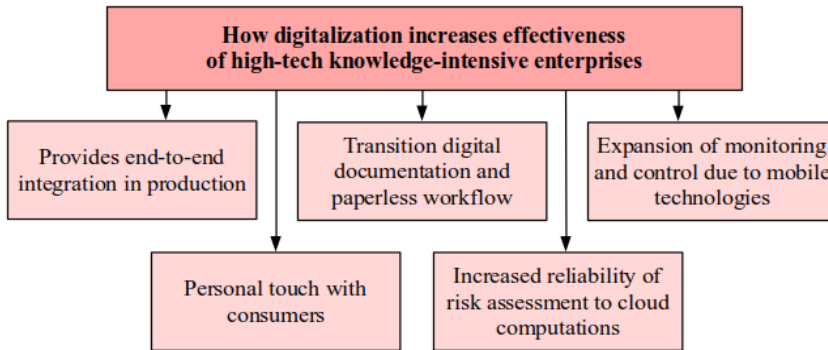


Fig. 1. The results of digitalization in the production activities of high-tech knowledge-intensive enterprises.

Speaking directly about the production of innovative products, thanks to digital technologies, the differentiation and optimization of production processes is accelerated. This helps to reduce costs and increase the competitive advantage of enterprises. Digital technologies have made it possible to automate many production processes, providing high quality and flexibility. A powerful impetus for improving the efficiency of production activities is the introduction of advanced production technologies and technological processes, including cyber-physical systems, machines, apparatuses, equipment and devices based on interaction in the digital environment [6,7]. Such technologies provide design and engineering, production, processing and assembly of products [10]. Of great importance is the simulation of the loading capacity of such expensive equipment. No less important are advanced manufacturing technologies that provide automated loading and unloading operations on automated storage systems using automatically controlled vehicles. However, their functioning is simply impossible without automated surveillance and control systems, operational communications and management through multi-level production information systems that provide integrated management and control. Therefore, the use of such technologies will provide not only more efficient interaction between participants in the production of innovative products, but also will accelerate the development and commercialization of innovations. Of course, the management of such complex production systems will gradually move from planning systems (ERP, MRP) and management (MES) to integrated work platforms CRM, BI, PLM, which include business tools for managing the supply of components and shipment of finished products, development and control for cyclical production schedules, the use of ready-made solutions and means of optimizing production processes without human intervention.

The results of using digitalization tools in the production activities of high-tech knowledge-intensive enterprises are presented in Fig. 2.

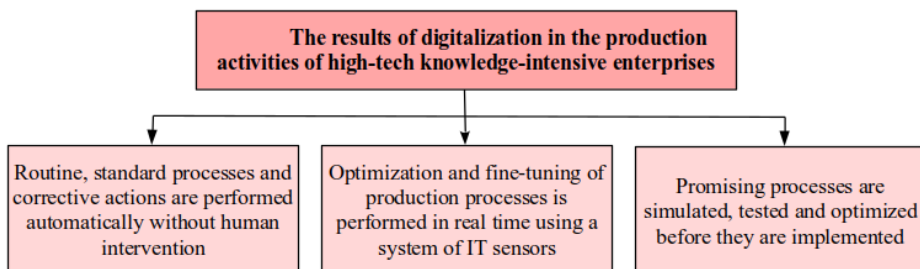


Fig. 2. The results of digitalization in the production activities of high-tech knowledge-intensive enterprises.

It is obvious that the adaptation of high-tech knowledge-intensive enterprises to the challenges of Industry 4.0 requires technologically competent personnel capable to work in such areas as: digital business, Internet marketing, digital development, advanced analytics, learn new technologies and maintain high-tech equipment. New realities repeatedly increase the importance and value of intellectual capital. Therefore, traditional personnel management systems, their training and selection should be transformed into structures for talent management, training and the development of creative abilities of employees. Therefore, it is necessary to develop the so-called “digital thinking” with appropriate cultural and psychological changes in the mentality of the staff.

In [18], it is noted that the staff not only ensures the growth of intellectual capital as a strategic asset, but also creates the conditions for the successful operation of enterprises. This puts forward special requirements for the staff according to its creative abilities, according to the criteria of novelty, usefulness and originality of ideas, as significant requirements of the 21st century. The study of the characteristics of a person as a subject of productive creative activity has become widespread not only in the domestic economy, but also in psychology [15]. Therefore, in our opinion, ensuring the success of innovative activities must necessarily be based on the effectiveness and motivation of the staff, its creativity and creative activity. Equally important is the ability of employees to continuously learn, acquire new knowledge, and improve professional skills. Motivational mechanisms aimed at organizing the process of reproduction of highly skilled and innovative employees, improving their professional skills and abilities can play a significant role in solving these problems [4].

The requirements for personnel, as an important factor for success in an ever-changing environment, are presented in Fig. 3.

The ever-increasing role of cooperation and partnership cannot be underestimated. Therefore, in addition to personnel, as noted in [2], the organization of the digital space itself, in which integrated digital platforms operate, is also important for the successful implementation of digital technologies.

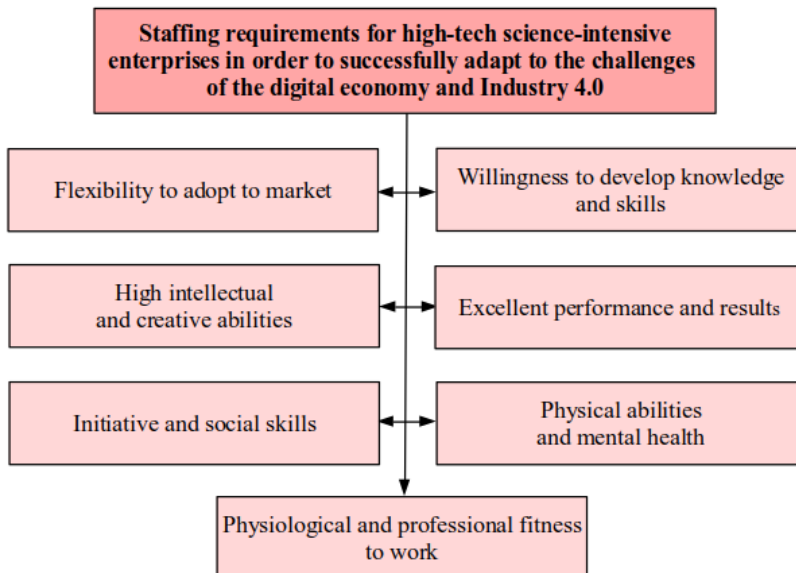


Fig. 3. Staff requirements in digital economy.

Such platforms of end-to-end digital technologies, in addition to providing communication channels for interaction between consumers and suppliers, should provide the ability to

integrate and exchange information between enterprise management systems and their high-tech equipment, as a significant step in implementing the concept of Industry 4.0. All this will ensure not only horizontal and vertical integration of enterprises, but also find other acceptable options for interaction, promising mechanisms for mutually beneficial cooperation [21].

4 Discussion

As the results of the study showed, successful adaptation to the challenges of Industry 4.0, high-tech knowledge-intensive enterprises is impossible without a radical restructuring of their digital infrastructure with the following qualitatively new properties:

- greater detail and personalization of offers to customers in the digital space;
- mobility, as the use of new mobile applications with enhanced functionality and remote access;
- socialization in personnel management with the improvement and development of the organizational and innovative culture of enterprises;
- new management capabilities through the use of modern digital technologies and software;
- expanding the scope for structuring and preparing for use arrays and databases of business intelligence tools with artificial intelligence;
- introduction of advanced manufacturing technologies and technological equipment, including cyber-physical systems, machines, apparatus, equipment and instruments based on interaction in the digital space.

Equally important is the assessment of the degree of readiness (adaptation) to the challenges of Industry 4.0. The assessment of the adaptation degree in world studies [12,13] is based on criteria such as the presence of digital development drivers (innovation, modern technology and infrastructure, human potential, the ability to access large trading platforms and attract investment, demand for products, resource support) and production and economic potential (the scale and complexity of production, the state of the material and technical base). However, the questions of how exactly these criteria can be used in assessing the success of enterprises adapting to the challenges of Industry 4.0 remain debatable.

At the same time, the results of the study made it possible to determine a number of system properties and patterns that determine the successful adaptation of high-tech knowledge-intensive enterprises to the challenges of Industry 4.0. First of all, these are obligatory components such as material resources, including technology and equipment, scientific and technical achievements, financial, personnel and information support, the presence of an organizational and economic mechanism for managing activities with wide adaptive capabilities. Their quantitative and qualitative characteristic is the innovative potential of enterprises, the management of which with the help of a special organizational and economic mechanism allows them to achieve significant success [16].

The analysis of innovative potential and its assessment is devoted to a number of works of domestic and foreign researchers. Thanks to their efforts, its optimal structure was determined [20], a system of characterizing indicators was created, and evaluation methods were proposed [3,9]. It is obvious that under the influence of the external environment, including the realities of the digital economy and the challenges of Industry 4.0, the innovative potential of high-tech knowledge-intensive enterprises is significantly changing. At the same time, its characteristic indicators will be supplemented. In this regard, when considering the possibility of using innovative potential as a tool for adapting enterprises to the challenges of Industry 4.0, the following provisions were taken into account:

- assessment of innovative potential should be comprehensive and as objective as

possible;

- such features as non-linearity, multidimensionality and nonequilibrium should be taken into account during measuring innovative potential and its structural components;
- dynamics of changes in innovative potential under the influence of factors of the external and internal environment of enterprises should be taken into account during choosing indicators.

To maximize the consideration of these provisions, we have summarized the opinions of experts obtained by the survey on the topic: “What additional indicators of innovative potential most characterize the digital transformation of enterprises and their adaptation to the challenges of Industry 4.0?” A survey of expert groups was conducted at 24 high-tech knowledge-intensive enterprises specializing in the development and production of innovative products.

Expert suggestions are summarized in the table.

Table 1. Indicators of the innovative potential of high-tech knowledge-intensive enterprises, characterizing their adaptation to the challenges of Industry 4.0.

Structural components of potential	The content of additional indicators
Organizational and managerial component	Level of automation of current management decisions,% (based on rigorous algorithms of MESS-systems or neural networks; expert assessment methods)
	The degree of distribution of R&D by performers (expert assessment),%
	The level of development of the corporate information system (score assessment)
	The presence of electronic document management (score expert assessment)
	Electronic interaction with counterparties
	The development of industrial analytics technologies, including cloud computing
Production and technological component	Level of automation of work,% (calculation by labor input or expert assessment is possible)
	The share of additive technologies in production,% 3D printing technology
	The degree of integration of equipment into a single information network
Marketing component	Product sales via the Internet
	Internet of things
Research and development	The share of developments carried out using cloud technologies,%
	Duration of new product development, years
Personnel component	Share of employees using digital technologies,%

Of course, the indicators given in the table should logically supplement the well-tested in practice standard set of indicators of innovative potential.

The approbation of a methodology for a comprehensive assessment of the innovative potential of industrial enterprises as a degree of their adaptation to the challenges of Industry 4.0 was tested at the high-tech knowledge-intensive enterprises “Shtorm” (Yekaterinburg) and “Tekhnotron” (Cheboksary). These enterprises are well known for their innovative developments in the field of welding production. Digital automata developed by “Tekhnotron” for orbital welding of oil and gas pipelines are successfully used at the facilities of the fuel and energy complex. Robotic systems for welding and surfacing developed by “Shtorm” are well-known in various engineering industries. These enterprises are actively engaged in innovative activities and have achieved significant success in a competitive environment. However, the practical use of the proposed

methodology for assessing innovative potential and comparing the changes in its characteristic indicators over the past five years showed that both enterprises studied have significant achievements in terms of adapting to the challenges of Industry 4.0, but they need further development of their innovative potential in order to move to a higher quality level of adaptation. In particular, the state of their fixed assets, the degree of automation of the work performed, and the level of development of industrial analytics, including cloud computing are of serious concern. Currently, based on the data obtained, both enterprises are carrying out comprehensive work to enhance the development and more rational use of their innovative potential, including replacing obsolete equipment, changing principles and approaches in organizing and managing production, selling products, and training and retraining specialists.

5 Conclusion

The theoretical, methodological and practical provisions formulated by the authors of this article about the conditions for adapting high-tech knowledge-intensive enterprises to the challenges of Industry 4.0 indicate cardinal differences between new ways of creating and commercializing innovative products from traditional ones due to the widespread use of digital technologies. Therefore, such enterprises in the conditions of the challenges of Industry 4.0 can no longer be limited to solving the traditional range of tasks, but must change approaches to their activities in the field of R&D, creation and commercialization of their products, taking into account the capabilities of modern digital technologies.

In this regard, high-tech knowledge-intensive enterprises in order to adequately respond to the challenges of Industry 4.0 should take into account the following circumstances:

- digital technologies significantly reduce the cost of R&D, creation and commercialization of innovative products;
- information exchange using modern digital technologies has become a full-fledged and significant factor in the implementation of innovative activities;
- availability of management information and increasing the efficiency of its processing methods helps to reduce the overall level of risks and uncertainty in innovation;
- digital technologies significantly increase the importance of specialists who are able to interact and maintain complex production and communication-information systems.

The results of the study also allowed us to determine a number of system properties and patterns that defining the successful adaptation of high-tech knowledge-intensive enterprises to the challenges of Industry 4.0, including the availability of mandatory components in the form of material resources, including technology and equipment, scientific and technical achievements, financial, personnel and information ensuring, the availability of an organizational and economic mechanism for managing activities with broad adaptive capabilities [24]. Their quantitative and qualitative characteristics may be innovative potential characterizing the capabilities, abilities and desire to succeed in a competitive environment. Thus, the procedures for assessing the innovative potential of enterprises can become an effective tool for determining both quantitative and qualitative indicators of enterprises, their degree of adaptation to the challenges of Industry 4.0. In addition, there is a real opportunity to assess the impact of planned measures on the innovative activities of enterprises, to determine methods and means of responding to the effects of external and internal environment [24, 25].

The proposed methodology for a comprehensive assessment of the innovative potential of industrial enterprises, as the degree of their adaptation to the challenges of Industry 4.0, was implemented at a number of high-tech knowledge-intensive enterprises specializing in the field of welding production. Its implementation contributed to the development and implementation of integrated measures for a more rational use of their innovative potential

in terms of their adaptation to the challenges of Industry 4.0.

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