Environmental safety at hi-tech enterprises in the application of artificial intelligence and Industry 4.0 technologies

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Abstract. The article systematizes theoretical and methodological provisions on the prospects of deployment of environmental safety, digital technologies, including artificial intelligence, industrial Internet, additive manufacturing and other elements of the "Industry 4.0" concept at Russian high-tech enterprises in order to improve the efficiency of finished products and dual-use technologies. Current and prospective areas of integration of "Industry 4.0" concept elements into production processes are considered, examples of successful cases of implementation of "Industry 4.0" technologies at Russian high-tech enterprises are given. The article identifies and analyzes the factors that stimulate and restrain the integration of the elements of the "Industry 4.0" concept at Russian high-tech enterprises. The results of the article can be used for further improvement of the state economic and legal regulation of digital technology development.

1 Introduction

One of the integral directions of the development of the high-tech industry at the present stage is the digitalization of production processes, including the use of artificial intelligence (AI). At the same time, digitalization is considered to be a necessary element of the "Industry 4.0" concept, which is expressed in both extensive and intensive penetration of cyberphysical systems into economic processes in order to increase their efficiency, as well as increase the output of products with new properties and increased operational characteristics [1-15].

The military-industrial complex (MIC) is undoubtedly a high-tech branch of the economy of the Russian Federation, the concentration of its scientific, technical and industrial competencies [6]. In the context of sharply increased needs for the intensification of the production of high-tech military, special and dual-use products, the defense industry can become one of the key drivers of the digital transformation of the domestic economy, through

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the gradual introduction of such elements of "Industry 4.0" as: smart manufacturing technologies, industrial Internet and the Internet of Things; 3D printing based on digital models (additive manufacturing); VR (virtual), AR (augmented) and XR (augmented) reality; ubiquitous robotization of production processes; planning and analytics based on big data (Big Data); artificial intelligence and blockchain; quality and product lifecycle management systems, etc. [2, 16-25].

At the same time, it should be taken into account that the above listed structural elements of the "Industry 4.0" concept can significantly increase the efficiency of both already deployed and prospective production processes related to the production of finished dual-use products (Table 1).

Table 1. Current and prospective areas of integration of Industry 4.0 elements into MIC production processes.

Structural element	Current area of integration into production processes	Promising area of integration into production processes
Additive manufacturing	Prototyping, production of functional end-use parts	Application of materials with new physical properties to qualitatively improve the characteristics of finished products
"Big data" analytics	Real-time monitoring of the condition of assemblies and units of products in the shipbuilding and aircraft industry, production planning and forecasting	Intra- and inter-industry databases updated in real time, including the ability to accurately plan production output and forecast market conditions; Updated databases of the nomenclature of manufactured products used in end products and components
Advanced robotics and cognitive automation	Application of CNC machines and industrial robots in aircraft and shipbuilding to improve product quality and reduce costs; non-autonomous and semi-autonomous ground, airborne and marine robotic systems	Automation of all production processes, automation of product acceptance and quality control, automation of product service; Autonomous robotic systems for ground, air and sea-based systems
Artificial intelligence	Technologies of "digital twins" of materials and products, intelligent digital modelling	Virtual testing, test beds, and polygons to reduce the number of costly physical and in-situ tests required to assess the quality of prototypes
Industrial Internet/Internet of Things	Tracking of in-plant cargo vehicles, RFID tags, sensors for monitoring the condition of assemblies and elements of complex products (aircraft engines, aviation fuel systems, etc.)	Reduction of material and related production costs based on "big data", implementation of integrated digital production assets, and ultimately - the transition to an autonomous digital production environment
Blockchain	Transparent and accountable data sharing between different sectoral actors	Registers data on the nomenclature and characteristics of products, components, cost of supplies, lead times processes
Digital reality (virtual, augmented and augmented reality)	Optical tracking of parts, assemblies and components of complex engineering systems	Application of digital reality to accelerate the training of qualified production and warehouse personnel, creation of simulators of production processes

In addition, the need for comprehensive involvement of defense industry organizations in the processes of digital transformation is dictated by the increased complexity of modern military, special and dual-use products, the growing share of multi-component materials in them, the intellectualization and informatization of their control systems, as well as the qualitative growth of their operational characteristics [26-35]. In this regard, it is necessary to note the converging role of "Industry 4.0", whose elements, due to a high degree of interoperability, transform dual-use from a side field into a space of mutual integration of complex technological, production and operational solutions for military, special and civil purposes. At the same time, the adaptability of such elements of Industry 4.0 as artificial intelligence, blockchain, digital twins, additive manufacturing and BigData systems can level the barriers that inevitably arise in the process of integrating the capacities of defense and civilian industries, simplifying the use of technological and production processes, production equipment, personnel and facilities to meet both defense and civilian needs of the country's economy (Figure 1).

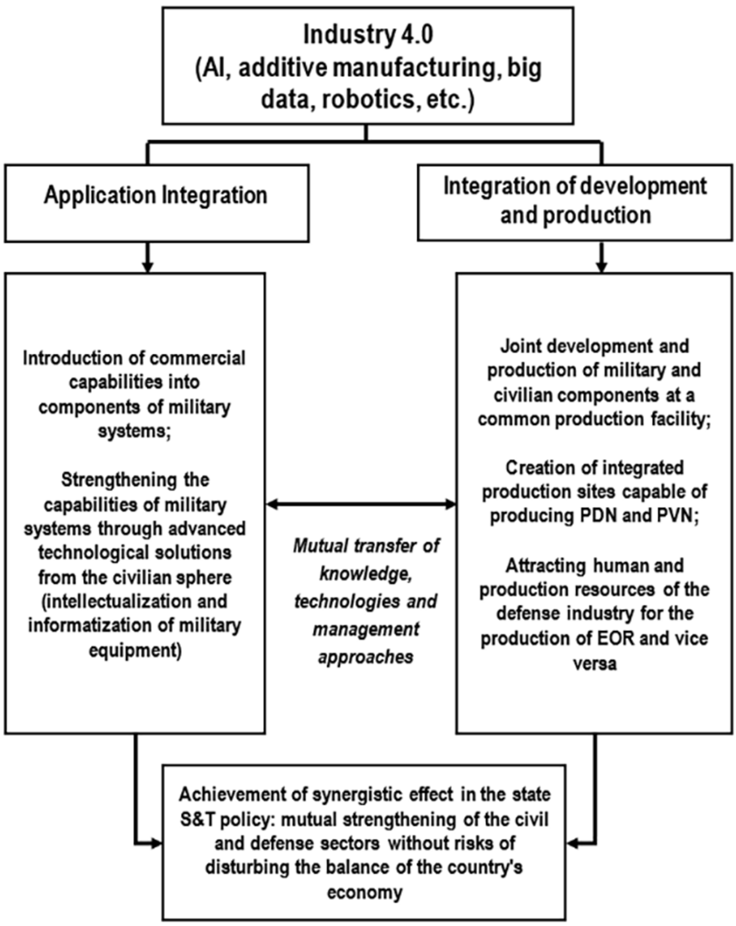

Fig. 1. Opportunities of Industry 4.0 in mutual integration of defense and civilian sectors of industry.

Digital transformation of high-tech industries can be one of the answers to the challenges of the new stage of development of the Russian economy, caused by the need to resist sanctions pressure, accelerate import substitution and, eventually, and the transition to technological sovereignty [7, 36-40].

In this regard, it seems relevant to consider the current state and prospects of integrating elements of the "Industry 4.0" concept and related technologies (including artificial intelligence and industrial Internet) at Russian high-tech enterprises of the defense industry in order to improve the efficiency of finished products and dual-use technologies. At the same time, it is necessary to identify the problems, factors and risks that hinder the integration of new production technologies at Russian high-tech enterprises.

2 Current state and prospects of integrating elements of the "Industry 4.0" concept at domestic high-tech enterprises

Digitalization and digital transformation of Russian high-tech enterprises are being developed within the framework of the implementation of the Decrees of the President of the Russian Federation dated May 7, 2018, No. 204 "On the national goals and strategic objectives of the development of the Russian Federation for the period until 2024" and dated 21.07.2020, No. 474 "On the national development goals of the Russian Federation for the period until 2030", including in order to address the task of ensuring the accelerated introduction of digital technologies in the economy and social sphere, the Government of the Russian Federation has formed a national strategy for the implementation of digital transformation and the introduction of elements of "Industry 4.0". At the same time, until recently, the issues of digital transformation and implementation of "Industry 4.0" elements were considered mainly in the context of improving the operational efficiency of civilian enterprises of the manufacturing industry, covering mainly the processes in the sphere of their resource and financial management [8]. At the same time, the defense industrial complex was not involved in these processes, relying on established practices of managing economic and production processes. Nevertheless, since 2021 there has been a tendency of steady growth of cases of integration of the elements of the "Industry 4.0" concept at high-tech enterprises of the defense industry, mainly in the field of digital (artificial intelligence and digital twins) and additive technologies.

As follows from the analysis, the largest number of successful cases of integrating elements of the "Industry 4.0" concept at high-tech enterprises of the defense industry is observed in the field of artificial intelligence and digital twins. This trend is confirmed by the data of production statistics of the defense industry enterprises (Figure 2).

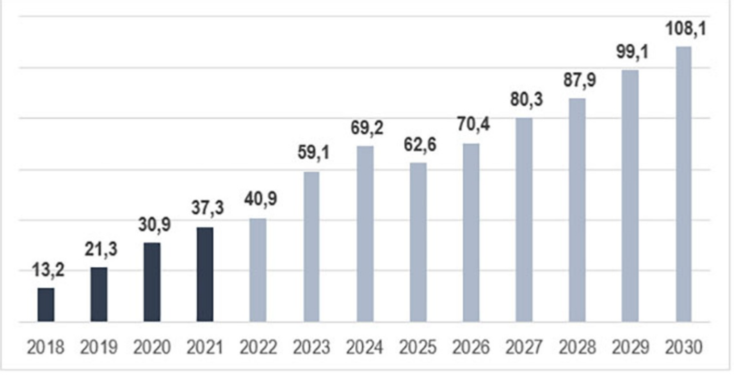

Fig. 2. Volume of production of civilian products by defense industry organizations using digital technologies in 2018-2022 with a forecast to 2030, bln. rub.

In turn, additive manufacturing technologies in the domestic defense industry are integrated mainly on the basis of the Additive Technology Center of the State Corporation "ROSTECH", which in 2022 increased the volume of production of aircraft engine building products by 3D printing by 179%, or 2.8 times. The observed trend allows us to forecast both further growth in the production of additive equipment and components and an increase in the share of defense industry organizations in this market.

At the same time, despite the positive trends, we can state an almost complete absence of examples of system integration of Internet of Things technologies, advanced robotics and cognitive automation, as well as Big Data analytics at domestic high-tech production facilities. Unfortunately, due to the lack of objective data, it is not possible to identify the true cause of the observed bias towards the integration of predominantly digital control technologies and additive manufacturing technologies. This is probably due to the prioritization of improving the efficiency of established and familiar business and production processes over the introduction of new management and production-technological solutions. Nevertheless, based on the study of the experience of digitalization at defense industry enterprises, it can be noted that in addition to subjective issues related to the priorities of organizations and their production specifics, the slow pace of implementation of Industry 4.0 elements is caused, among other things, by objective problems in managerial and organizational approaches. For example, an undoubtedly hindering factor is the insufficient pace of the processes of technical re-equipment and productivity improvement of the defense industry organizations, the wear and tear of their production assets, low digital competencies of employees at outdated production facilities. An important negative role is also played by bureaucratic barriers that prevent the rapid introduction of changes in production and technological processes, the need to conduct approval procedures, confirmatory tests, etc. [9] Undoubtedly, this is due to the specifics of manufactured products, strict requirements for their acceptance within the framework of the state defense order, which leads to the oversaturation of production processes with control and documentation operations. In this regard, it seems relevant to consider the issue of reducing administrative and regulatory barriers to the integration of new production technologies.

There are also negative practices caused by managerial distortions, namely: reinsurance of work performers, associated with concealing the true volume of stocks of materials and work in progress, overestimation of requirements for deadlines [9]; formal approach of enterprise management to the implementation of digital systems of production process management, quality management and lean manufacturing; lack of clear goal-setting, transparent and enforceable targets of digital transformation of production processes at the enterprises of the military-industrial complex. The latter circumstance is caused, among other things, by the insufficient development of a set of standards for the digital transformation of the defense industry, national standards in the field of artificial intelligence, SMART-standards, standards for ensuring interoperability in the interests of defense industry enterprises.

3 Conclusion

Summarizing the results, we note that the acceleration of the integration of the elements of the "Industry 4.0" concept at domestic high-tech enterprises depends on many factors, the genesis of which is determined by the complexity of the domestic defense industry at the present stage as a multi-structural system, formed in objective historical conditions of forced transformation of high-tech industries from exclusively planned methods of economic management to market-based, based on integrated structures. The following key factors that stimulate and limit the integration of the elements of the "Industry 4.0" concept at domestic high-tech enterprises can be distinguished.

The adoption of digital technologies, artificial intelligence technologies and, ultimately, the transformation of manufacturing processes is not a pure IT project. Both on the scale of an individual organization and on the scale of the industry as a whole, we are talking about the transformation of production processes, not the simple digitization of some operations.

In this regard, it should be noted that the digital transformation of the defense-industrial complex, the introduction of elements of the Industry 4.0 concept into its production processes, is a multifactorial process that addresses regulatory, legal, organizational, methodological, economic and social, scientific, scientific and technical, military, technological and production issues.

Special attention should be paid to intra- and inter-industry cooperation when implementing digitalization processes in the defense industry and full-scale integration of functional elements of the Industry 4.0 concept into it. The defense-industrial complex of the Russian Federation is represented by organizations and integrated structures that have significant differences in their business models and production activity profiles. Therefore, the coordination of actions of defense industry organizations to introduce new digital technologies into production processes requires a single center with competencies both in the issues of improving the efficiency of business process management at high-tech enterprises of the defense industry complex and in the classification of new types of products manufactured with the use of artificial intelligence, additive technologies, robotics, etc.

Currently, in accordance with the instructions of the Ministry of Industry and Trade of Russia, FSUE VNII Center is solving the tasks of identifying defense industries that can be used to produce high-tech civilian and dual-use products using digital technologies, artificial intelligence and other elements of Industry 4.0. Nevertheless, despite the importance of a centralized approach to digital transformation, it must be emphasized that its success is critically dependent on establishing trust-based cooperation between all participants in economic activity – enterprises of the military-industrial complex, academic institutes and research organizations, large technology companies and small private innovation teams within the framework of a single regulatory, communication and cooperative environment of mutually dependent development, with mechanisms for the transfer of knowledge, technological and managerial decisions.

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