Digital transformation of machine-building complex enterprises

S V Novikov and A A Sazonov
Moscow Aviation Institute (National Research University), Volokolamskoe highway 4, 125993, Moscow, Russia

E-mail: ncsrm@mail.ru

Abstract. The article is devoted to the analysis of the digital transformation of machine-building complex enterprises. In the theoretical part it is determined that the development is possible due to the effective and qualitative renewal of existing production and business processes on the basis of comprehensive introduction of advanced innovations. There are key business objectives of the technological concept «Industry 4.0» in the article. There are also factors influencing the indicators of competitiveness of Russia in the implementation of the concept of technological breakthrough. In the research part of the article the influence of digitalization processes on the competitiveness of products in the digital production is determined. The «roadmap» is made in accordance with the provisions of the program «Digital economy of the Russian Federation» and «Digital engineering». As a result of the analysis, it was determined that in the developed program, the main importance, of course, is the development of special standards necessary for the qualitative development of the digital architecture of the enterprise. In conclusion, the authors shown that it is necessary to have certain competencies of employees working at the enterprise, as well as the management should understand the growing need to create new jobs for highly qualified specialists processing and analyzing production information within the production enterprise for a competent digital transformation.

1. Introduction
The enterprises of the machine-building complex are a key component for the domestic high-tech industry, and they determine the technological independence, economic potential, and defense capability of the Russian Federation. The transfer and adaptation of Japanese approaches, as practice has shown, have results, but only partial ones. «Industry 4.0» is a tool for transforming an enterprise’s business model to a new level of efficiency, i.e. transition to a fully automated digital production controlled by intelligent systems in real time in constant interaction with the external environment, going beyond the boundaries of one enterprise, with the prospect of combining things and services into a global industrial network. The development of digital transformation by enterprises of the machine-building complex involves the effective and high-quality updating of production and business processes based on the comprehensive introduction of advanced innovations. An important step in the development process is the need to adapt updated business processes to the key requirements of the digital economy. The task of digital transformation takes into account the fundamental foundations of the work of various intersectoral systems and technological chains, which means that it is almost impossible to efficiently solve it within the same industry. Therefore, the only right way will be to create a single integration
center, as well as a platform for finding optimal solutions, on which all participants of the digital transformation will be presented without exception.

2. Theoretical part

Over the past two decades, there has been a radical diversification of the infrastructure of the aviation complex. As a result of this fact, the competitiveness of the products of domestic enterprises in foreign markets has significantly decreased, the needs of many types of products in the domestic market have also decreased, and, consequently, production volumes in the defense industry, agricultural machinery, aircraft manufacturing, and other industries have reduced. The negative impact of these processes is especially obvious in the domestic machine-tool industry, which largely determined the high degree of import dependence of the leading branches of machine building on foreign suppliers of innovative technologies, equipment, and industrial automation systems [1]. In the effective implementation of the state policy of the Russian Federation aimed at creating the necessary and comfortable conditions for the qualitative development of the components included in the digital economy, the formation of an integrated digital environment and the development of technological platforms are the most important things. By the end of 2030, high-tech enterprises should ensure the manufacture of at least 60% of civilian products, which will significantly increase the current level of competitiveness, based on the digital transformation of all aspects of the functioning of enterprises without exception [2].

Now, the promising industrial appearance of the enterprises can be described very briefly as the industrial internet as the usual virtual network or the fast-growing internet of things. Of course, this analogy is very superficial, since in the real sector there are quite material machines, people, and relationships behind the digital image. But the main thing is the global nature of resources (information, production, and logistics) and their adjustment to an individualized product. The technological concept «Industry 4.0» should solve the following key business tasks [3]:

- to ensure the transition to an individual product, without significantly increasing the cost of identifying these individual requirements;
- to expand the concept of the product, without limitation of alienation at the moment of sale, to accompany the user during all product life cycle;
- to maintain and expand (to the notorious limit) technological specialization of the involved business participants for not to lose the already achieved level of productivity;
- to ensure the functioning of all (and independent) business participants in an inextricable process with high requirements for efficiency and flexibility.

The above-mentioned directions of changes and tools are arranged in order of importance for the transition to the concept «Industry 4.0» and at the same time difficulties in implementation. Transition of enterprises to a new business model is partially realized now in some advanced segments of the domestic economy (complex engineering, defense industry, and aircraft manufacturing). Enterprises working in this concept involve a much wider variety of resources, technologies, and connections in the business and individualize their product. To maintain the integrity of the business, as well as to take advantage of the new business model, it is necessary to have an appropriate effective management system. It should have a very limited “human” component, be automated to a greater extent than, for example, production links [4]. The foundation for creating a holistic digital environment within the framework of the concept «Industry 4.0» is the widespread use of digital technologies at all levels and stages of industrial high-tech production. Creating a digital environment allows you to significantly optimize the time involved in the process of introducing new products to the market, increase the degree of flexibility of the production process and, as a result, improve the quality of products. As a result, it will allow domestic industry to reach a fundamentally new qualitative level. Now we are going to analyze the fundamental factors affecting the processes of digitalization and the growth of the digital economy (figure 1) [5].

Leading experts identify three levels of digital technology adoption:
1) Service technology. Here with the help of programs or something else we make traditional technologies a little better. For example, we can reach a remote source of information, make an appointment with a doctor, etc. These are obvious and understandable things. There are a lot of them, and the internet is one of the applications. Such projects are developing quite actively. If the state is going to help, it will be good, and if it is not, there will be no problem. The state support here should be not financial, but just infrastructural and organizational one.

2) Digital technologies, which in some part are changing the established structures of enterprises. For example, there was an enterprise where there was no computer numerical control (CNC) machine, and now there were 2 or 3 ones. The resource of the enterprise has not changed, but the possibilities have changed (more important level).

3) Digital technologies should lead to the emergence of fundamentally new opportunities in the industry, new technologies, and new types of enterprises. Here we are talking about a new technological structure, and this is the direction of the main blow of financing and state support [6] (the most important level).

**Figure 1.** Factors affecting the competitiveness of Russia in the implementation of the concept of technological breakthrough.

The state is now implementing a program of support for domestic producers, including aimed at import substitution. The tasks of import substitution are the excessive load for many manufacturers. The vast majority of digital solutions now depend on foreign software products. The correct integration into the already existing world engineering environment is also very important. Today it is already impossible to “come” there with the product. You need to have ideas, perhaps, of young people from...
universities and academic institutions. It is necessary to try, and then practically implement them. An important issue is the organizational form, because you need not only to build such long chains of the status of a university or academic institution, but also new end-to-end systems, which will allow getting the expected result [7].

In order to implement the import substitution program for obtaining state support measures, it is necessary to have the conclusion of the Ministry of Industry and Trade of Russian Federation on the manufacture of products on the Russian territory. It is issued on the basis of documents (acts of examination and certificates of origin) received by manufacturers in the Chamber of Commerce and Industry of the Russian Federation (RF CCI). The requirements of the Decree of the Government of the Russian Federation of July 17, 2015 № 719 include the requirements for the introduction of digital technologies at the enterprise. For example, for machine tool products, the share of production localization, which should meet the requirements, can be immediately increased to 15% due to the fact that a domestic control software and hardware complex is used. This is a fairly high share, but the experience that we have in RF CCI suggests that, unfortunately, actual domestic complexes are almost not used in machine tools. For some types of products, there are only requirements on the availability of rights to domestic software.

Digital transformation involves the transfer of production processes to a new technological structure, entails significant cost optimization, increased efficiency and productivity, and contributes the promotion of competitive domestic products on global markets that meet all modern technological requirements. The impact of digitalization on product competitiveness in digital production is presented in figure 2 [8].

**Figure 2.** Impact of digitalization on product competitiveness in digital production.

The Industrial Development Fund, within the framework of the implementation of the «Industrial Digitalization» program, finances projects of the introducing digital and technological solutions at enterprises in the real sector of the economy. Under this program, soft loans are provided at 1% in case of using Russian software for the entire term of the loan, in other cases there are 5% per annum. These mechanisms are aimed at stimulating both demand and supply for products of Russian manufacturers of industrial software, hardware, and software systems.
3. Methodology

There are the following research methods: analytical assessment of the forecasts of development technologies for the construction and development of digital engineering enterprises. The analysis is based on the study of the main provisions of the programs and activities stipulated by the Federal project «Normative regulation of the digital environment» of the national program «Digital Economy of the Russian Federation» and the action plan (roadmap) to improve legislation and remove administrative barriers in order to ensure the implementation of the National Technology Initiative in the direction of «Technet» (advanced manufacturing technologies). The program focuses on the «Development Strategy of the Information Society of the Russian Federation for 2017–2030» and assumes that the digital economy is an economic activity in which the data presented in digital form is a key factor in production. In accordance with the provisions included in the data presented in digital form is a key factor in production. In accordance with the provisions included in the «roadmap» formed on the basis of the above-mentioned program, the effective implementation of the «Digital Engineering» project is possible with the consistent implementation of the following key areas [9]:

1. Normative standardization and regulation. It is necessary to begin the formation of «Competencies Centers» in the field of digital engineering, unified methodological concept for the development of engineering necessary for the legal regulation of the use of digital data in the electronic environment, and specialized «Program Committee» to develop national standards and ensure regulatory and technical regulation in the digital engineering environment, based on a single architectural approach, considering the subsequent development of fundamental standards as soon as possible [10].

2. Creation of a unique unified platform and development of the concept of import substitution of software products necessary for the qualitative development of the information infrastructure of digital engineering. It is necessary to develop by domestic engineers and specialists of a single digital platform «Digital Engineering» that allows the collection, analysis, storage, and use of data necessary to fully meet the needs of high-tech enterprises and scientific and educational institutions, to develop the basic architecture of the digital engineering environment for the competent and timely management of digital counterparts of enterprises, products, and equipment. Digital production double is a guarantee of timely access to certification within a certain time frame and budget with the required quality. It is used at the very early stages of production planning for a future product, for example, for production simulation. A digital machine-building enterprise must use domestic software products, and, therefore, it is necessary to complete the development of a 3D-core, which will make it possible to create a unified architecture on its basis in the future [11].

3. Development of certain technological assets and research competencies. It is necessary to create a corporate portal that helps to collect, process, and analyze the various capabilities of a machine-building enterprise in the field of analysis and evaluation of the use of innovative technologies. It should facilitate the organization of effective partnerships between leading scientific, educational organizations, and business communities a lot. The creation of specialized centers implementing key areas of development of domestic digital engineering will simplify the process of coordinating the activities of Information Technology (IT) companies and develop promising products in a single information environment, based on common standards of digital engineering [12, 13].

4. Development of the information infrastructure necessary for the comprehensive implementation of educational programs, training, and advanced training. The creation of a unique educational center «Virtual Machine-Building Enterprise» will allow training and retraining of the necessary personnel for the digital economy, while attracting about 6-8 leading technical universities. Using cloud technologies and high-precision computer modeling, it is possible to develop a special profile necessary for the organization of digital engineering. To account for and track the best personnel, it is necessary to create a new generation environment (information and education), as well as an independent center for certification of personnel from the enterprise [14, 15].

5. Using advanced information security systems. Updating existing and developing new requirements for regulatory and methodological documents necessary to ensure the security of the information and technological environments of digital engineering. Updated requirements should take
into account the conditions of use of the industrial internet, machine-to-machine networks (M2M) that automate important processes, especially in the field of measurement, control, and monitoring. Areas of application include energy networks («smart grids»), production management, logistics, marketing, security, customer relationship management, etc. [16].

4. Results and discussion
In the developed program, there is the development of special standards necessary for the high-quality development of the enterprise’s digital architecture, and it is very important. The standards should be based on the principles of harmony with the fundamental international standards and also the principles set forth in the technological concept «Industry 4.0». Therefore, it is necessary to take into account trends in standardization, initiated at the regional, national, and international levels. Some associations are interested in this concept, for example, VDI (“Verein Deutscher Ingenieur” - Association of German Engineers), VDMA (“Verband Deutscher Maschinen und Anlagenbau” - Mechanical Engineering Industry Association), DKE (Deutsche Kommission Elektrotechnik Elektronik Informationstechnik - German Commission for Electrical, Electronic & Information Technologies), etc. International organizations are also interested and are developing standardization in the field of management automation and the industrial internet. As a part of the development of digital technology, it is necessary to create a specialized center for virtual prototyping. Its main task will be to ensure the effective decision-making by the chief designer in the process of communicating with own technological and production units. Virtual prototyping plays a key role at all stages of the life cycle and includes in its composition the following [17]:

1. Organization of the preliminary design process:
   1.1. Direct work on virtual prototyping of products, processes of technical production, and use (created digital layout should have the maximum degree of realism). It is also desirable to completely abandon the various physical layouts inherent in the initial stage of development.  
   1.2. Possibility to discuss future layout with customers, i.e. direct involvement of the customer in the adjustment of the performance characteristics.  
   1.3. Diagnostics to determine the degree of maintainability.  
   1.4. Real-time virtual analysis of ergonomic indicators. There is no need to create full-scale models.  
   1.5. The possibility of visual contact with potential customers (conducting personal product presentations).

2. Production planning:  
   2.1. Ability to present data in the most detailed and realistic way (to describe in detail the technological process of production).  
   2.2. Effective and fast simulator of imitation of manual processes (welding, painting, working with metal, etc.).  
   2.3. Organization of visual communications on a single layout of the production process.  
   2.4. Prototyping non-mechanical operations with the possibility of creating training videos.

3. Exploitation:  
   3.1. Significant increase in performance due to the integrated use of prototyping of the product under various conditions.  
   3.2. Ability to create procedural simulators.  
   3.3. Use of special CNC machines with the use of modern multi-axis processing at the enterprise. For example, at international enterprises, NX multi-axis machining is used, which allows producing high-precision parts of complex shape for a minimum number of operations and installations, helping to reduce the cost and production time. NX CAM program supports various methods for accurately determining tool orientation in multi-axis machining of complex surfaces, providing effective control of collisions and notches. Siemens PLM Software NX CAM is a comprehensive solution for developing control programs for CNC
equipment (CAM), post-processing, and simulation of machine tools. It allows doing the following:

3.3.1. Reducing design time by 30% due to multi-axis machining. Five-axis machining allows processing high-precision parts of complex shape for a minimum number of operations and installations.

3.3.2. Reducing the time needed to create programs for CNC machines by up to 90% due to the fused deposition modeling (FBM) technology, which automates the process. This technology allows automatically recognizing and creation of programs for various processing elements: prismatic, turning, electrical discharge, based on color, and attributes.

3.3.3. Easily switch from plotting to 3D modeling. Step-by-step training materials and intuitive Siemens NX interface allow quickly creation of 3D models parts and assembly units.

3.3.4. Improving the result due to advanced functionality. For example, the integrated simulation module of the machine operates on the basis of the UE code obtained from the NX postprocessor, and not on the basis of the tool path. Thus, NX provides a higher level of program verification directly inside the CAM system.

As a part of the technological transformation of machine-building enterprises, it is possible to create a specialized center for virtual prototyping. Now we are going to consider the financial aspects of operating a virtual prototyping center with the following example: existing virtual prototyping center that was built for the F35 program. Ship/Air Integration Lab (SAIL) is using of CAD software platforms such as Catia, Delmia. According to Lockheed Martin Corporation, costs is about 6.8 million dollars, and returns is about 76-110 million dollars, i.e. investment efficiency was 1 to 14-16. This effectiveness of investments in virtual prototyping centers correlate with data on the automotive and oil and gas industries [18]. At the same time, this Corporation used a special parameter “X”, it is a relative estimate of the cost of a possible correction of an error received in the product design process or adjustment of the product’s manufacture technology at various stages of development. Therefore, if the error was not immediately determined by the specialists and not corrected in the first year, then the cost of this adjustment will increase 2-5 times in a year of the project, and 10 times in 5 years. According to the company’s experts, it made it possible to correctly compose and work out the program in the early stages, avoiding a large number of adjustments and corrections at the final stages.

5. Conclusions

The digitalization process of high-tech industrial and economic systems has quite diverse forms of manifestation. Most of the domestic enterprises have a fairly high degree of automation of existing production processes, and some of them are already building unique data processing centers and are gradually introducing cloud solutions for storing a huge amount of data. The transformation should be carried out under the scrutiny of management, experts, and specialists and should not be limited in resources. A competent digital transformation requires certain competencies for employees working at the enterprise, and management must also understand the growing need to create new tasks for highly qualified specialists who process and analyze production information within the manufacturing enterprise.

The effective use of key digital technologies in the domestic industry will require substantial modernization of the current regulatory framework. Proper clarification and subsequent adjustment of the legislative framework is necessary to create the level of trust and legal certainty for all areas of industry. Digital technologies are characterized by high development speed, therefore it is very important to ensure that the legal framework is always updated taking into account current technological development trends. In the future enterprise management will need to include issues related to the cybersecurity of industrial systems in its field of vision. Comprehensive data protection should be one of the main principles for pushing high-tech enterprises to advanced developments implemented in the field of personal data protection.
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