Digital twin as a driver of digitalization of organizations' activities and creation of digital models

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Abstract— This article discusses the positive and negative aspects of the transition of organizations to digital activity, as well as the problems encountered on the way of organizations in digital activity transformation and the use of digital twins. The main national programs of the Russian Federation for the development of new breakthrough technologies are described. A simulation model of the operation of a multiple access system with synchronous-time access to the on-air data transmission medium is presented. It is used to justify the correctness operation of metamathematical model, which was designed using the AnyLogic software product.

Keywords - simulation model, mathematical model, digital twins, digital transformation, breakthrough technologies, digitalization of activity

I. INTRODUCTION

From 2000 to the beginning of 2010, the potential for productivity growth in most developed countries in the conditions of economic and technological mode began to run out, thereby leading to significant decrease in productivity, sharp drop in return on investment due to traditional technologies reaching their "ceiling" of productivity, which could not be solved only with the help of public policy on the application of macroeconomic measures. Under these conditions, countries began moving to new models of management.

Humanity is entering a new era, the era of intelligent technologies. Everything that surrounds us is rapidly changing and evolving. We are entering an age where intelligent systems are able to perform the functions of optimization, decision making, automatic analysis and many other functions while interacting with the real world in real time [1]. We call all these large-scale changes taking place in the industrial and economic sphere the “Industrial revolution”, or “Industry 4.0”, which is based on the transition from mass production of standardized products to flexible high-performance one that produces individualized products.

Recently, there has been a transformation of activity models in various fields, caused by new "breakthrough" digital technologies, which should ensure the international competitiveness of both the entire country and individual companies that form the infrastructure for digitalization. One of the main impulses is the exponential growth in the diversity, quantity and quality of information, as well as the relationship between various areas of life.

Industry 4.0 involves the creation of cyber-physical systems, through which real objects are connected to information processes or virtual objects through information networks and the Internet. This revolution includes a number of breakthrough technologies that contribute to the revival of the venture capital segment, as well as intensive efforts in the field of these breakthrough technologies. In Russia, on June 4, 2019, the national program "Digital Economy" was adopted during the meeting of the Presidium of the Presidential Councel. This program includes the following main general purpose technologies:

- big data;
- neurotechnologies and artificial intelligence;
- distributed ledger systems;
- quantum technologies;
- new production technologies;
- industrial Internet;
- components of robotics and sensorics;
- wireless communication technologies;
- technologies of virtual and augmented reality.

II. ANALYSIS OF TRANSITION TO DIGITAL ECONOMY

The explosive development and spread of new technologies, their penetration into all spheres of human activity has already begun to lead to rapid and profound changes in global market, structure and nature of modern industrial production, economy and social sphere.

In the "Strategy for the Development of the Information Society in the Russian Federation for the period 2017 - 2030" definition is given: "digital economy is an activity in which the key factors of production are data presented in digital form, and their processing and use in large volumes (including directly at the time of their formation) allows to significantly increase efficiency, quality and productivity in various types of production, technologies, equipment, storage, sale, delivery and consumption of goods and services" [2].

Transition to digital economy requires significant transformation almost all areas where business interacts with people, society and government: technology, organizational structure, staff competencies, supplier relationships, business models, target markets, product and service portfolios, mechanisms of labor remuneration, intellectual property rights, legal contracts, taxation, accounting, customer relations and others [3]. It is important to note that any changes lead to both positive and negative consequences (Table 1).

Table 1. Positive and negative results of transition to digital economy

Positive issues	***Negative issues***
– production of new products and services, – opportunities for geographical and functional expansion of trade, – increase in labor productivity, – improving the efficiency of all industries, – improving the quality of products, – increased competition.	– possibility of mass unemployment, – risk of reducing the income of total population, – fundamental change in many foundations, – disappearance of entire sectors of economy, – disappearance of many specialties, – new security issues.

In order to see all fundamental technological tasks that need to be solved when building new models of activity in digital economy it is advisable to apply an architectural approach. The architecture of digital economy in the form of stratified hierarchical model, which contains two groups of levels (infrastructural and subject-oriented) is presented on Figure 1 [4].

New solutions are emerging at the intersection of several digital technologies. A prime example is the concept of digital twins, which combines technologies of computer-aided design, modeling of physical processes, cloud computing, the Internet of things, artificial intelligence, machine learning and increases the range of digital technologies used as they become available.

A cyber-physical system is the interaction between digital twins and physical object, which is a complex system of computational and physical elements that constantly receives data from the environment and uses these data for further optimization. The “core” of the system in the form of AI (artificial intelligence) and other technologies receives data from sensors in the real world, analyzes these data and uses them to further control physical elements. Due to this interaction, the cyber-physical system is able to work effectively in changing conditions in real time.

The concept of creating digital twins can be traced from the creation of physical products to virtual models of twins. Having gone through certain stages, from writing a plan on paper to creating models on a computer, you can see that at each new stage, new digital technologies and methods of modeling, forecasting, analysis, and training were added to the concept.

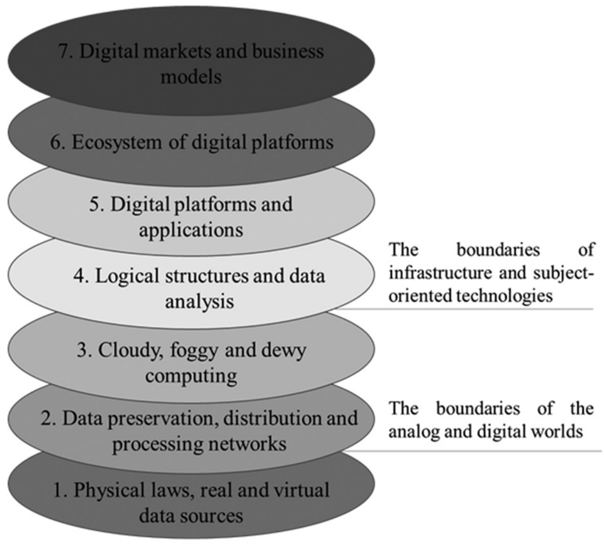

Fig.1. Architectural model of digital economy

A digital twin, according to classical definition, is a digital copy of living or artificial physical object [5]. The term digital twin refers to digital copy of potential and real physical assets (physical twin), processes, people, places, systems and devices that can be used for various purposes. Digital twins are designed to facilitate the means of controlling, understanding and optimizing the functions of all physical assets, ensuring smooth data transfer between physical and virtual world [6].

The definitions of digital twin vary due to the scope of its application. In relation to production processes, digital twin is a digital model of some physical entities created in cyberspace that interact in real time. In relation to this model, physical entity is original.

III. DIGITAL TWINS IN OPTIMIZATION OF MANUFACTURING PROCESSES

Manufacturing processes are becoming more and more digital; this trend has high speed and huge opportunities. Digital twins in enterprises work as following: data collection and cleaning, then data enrichment, and at the last stage, unique knowledge about process or object is obtained.

It is also worth noting that with the digitalization of production new business models will be built in any case. So digital twin is the best solution for demonstrating how this or that development will work. Digital twin is not only a visualization of physical object, but also insertion of all physical models in it, which will accurately describe its behavior. Some experiments can be carried out while creating such complex model; this mechanism of testing will not lead to high costs. After designing twins, it is necessary to verify all its models. The use of digital twins is aimed at reducing the time spent on developing new technologies.

Nowadays the digitalization of industry is no longer a fashion trend, but a necessary condition for maintaining competitiveness both in domestic and global markets. The development and implementation of advanced technologies requires large financial investments from organizations, which slows down the process of transition to "digital world".

In our opinion, this process (the process of using digital twins in organizations) is hindered by the following factors:

1. Lack of highly qualified personnel.
2. The absence of unified methods for verifying digital models.
3. Lack of payback of this technology in the shortest possible time.
4. Large financial investments in the concept of digital twins.

In 2021 research and consulting company Gartner in its report updated the maturity curve of emerging technologies, one of which is the digital twin (Figure 2). According to the result of research, it can be concluded that we need more than 10 years to increase labor productivity with the help of digital twin technology.

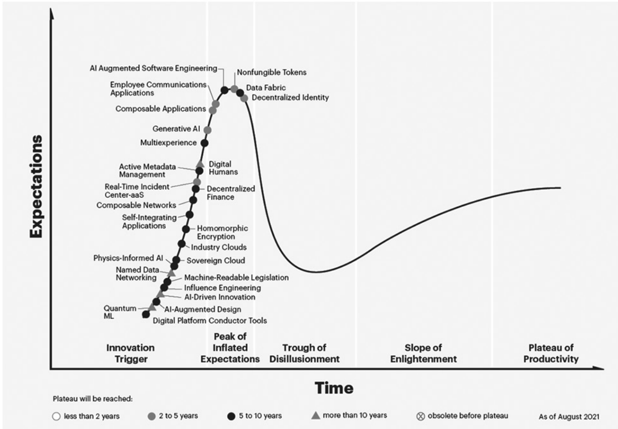

Fig.2. Hype Cycle for Emerging Technologies, 2021 [7]

Specialists of the Center "New Production Technologies" of Peter the Great St. Petersburg Polytechnic University (SPbPU) together with the specialists of Russian Federal Nuclear Center - All-Russian Research Institute of Experimental Physics (VNIIEF) in accordance with the "Program of National standardization for 2020" and the "National Standardization Program for 2021" developed the national standard GOST R 57700.37-2021 "Computer models and simulation. Digital twins of products. General Provisions" [8].

Within the framework of developed standard, for the first time such definitions as “model adequacy”, “product model validation”, “digital product model”, “digital (virtual) tests”, “digital (virtual) test bench” and “digital (virtual) testing polygon” are given.

The digital twin of product is based on digital model of product, which in turn is “a system of mathematical and computer models, as well as electronic documents of product that describes the structure, functionality and behavior of newly developed or operated product at various stages of life cycle, for which, based on the results digital and (or) other tests in accordance with GOST 16504, an assessment of compliance with the requirements for the product was completed ... ".

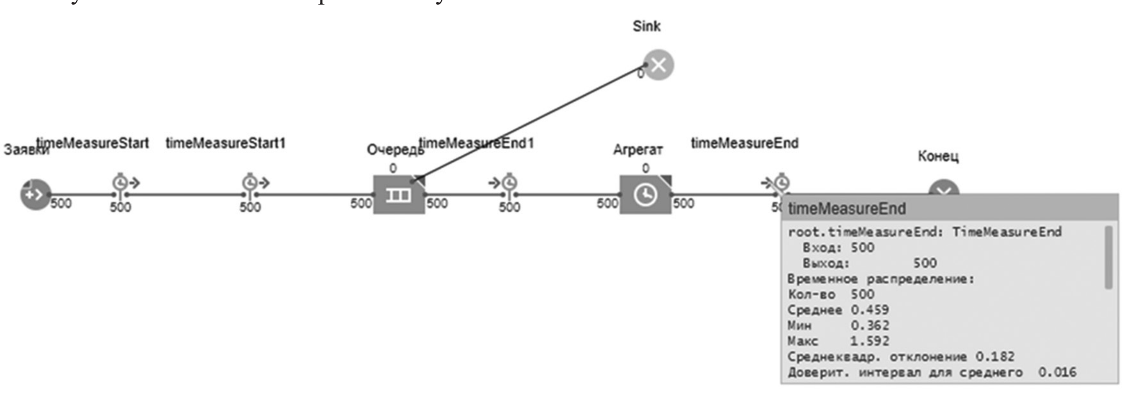

Fig.3. Simulation model

IV. BUILDING A SIMULATION MODEL

Verification of models with data from the real world implies the automatic supply of mathematical and simulation models of digital twin with structured up-to-date initial data from basic information components that describe the system in various aspects and are filled from related software systems in real time as they arise.

On the basis of WSN (wireless sensor network), the interaction of IoT smart things (which is one of the technologies of digital twins) is implemented [9,10]. The life time (or working time) of WSN is determined by the period of life of each thing included in its composition. As a result, when studying the processes of functioning of the WSN, an assessment of energy indicators of information interaction of smart things is considered as a necessary task.

When developing a simulation model, a multiple access system with synchronous-time access to on-air transmission medium was taken. It can be represented by the M/D/1 queuing system.

In the course of analytical solution, formulas were obtained and probabilistic-temporal and probabilistic-energy characteristics were calculated [11]. So the simulation model will determine which parameters affect the simulated system and how these parameters are related to each other.

To assess the quality of information interaction – random process of transmitting messages in WSN of the Internet of things – we use given mathematical model [11].

Based on it, we will write the final formulas for calculating the BTC (probabilistic-temporal characteristics) of the process of transmitting messages to WSN:

$$\bar{t} = \frac{N \cdot T_{\text{ок}} \,(\lambda \cdot N \cdot T_{\text{ок}}\text{-}2)}{2(\lambda \cdot N \cdot T_{\text{ок}}\text{-}1)} \quad (1)$$

where, N is the number of smart things, T_{ok} is the time interval reserved for each station, λ is the intensity of the message receipt for transmission.

To substantiate the correctness of metamathematical model, a simulation model was designed using the AnyLogic software product. This simulation development environment is one of the few programs that support multimethod simulation, which gives great opportunities in creation and implementation of digital twins.

The simulation model is shown in Figure 3. It includes several related modules: Request - the flow of request arriving in the system, Queue - the queue of application awaiting the receipt of application in the system, Server - a device processing the flow of requests, End - the end point of requests. To measure indicators in the model, timeMeasureStart (the beginning of the measurement period) and timeMeasureEnd were added (the end of the measurement period). If the request does not wait for receipt, then the queue can discard it in Sink (end).

The simulation was carried out with the following initial data λ=1 [s], $N \cdot T_{ok}$=0,362[s], N=15000, T_{ok}=0,000024[s].

As a result of the work, the program provides probabilistic-temporal characteristics for analysis according to the M/D/1 model, such as: the number of requests in the queue, the average time the request was in the queue, the number of requests left the system and the average time of requests in the system in general.

V. CONCLUSION

Conducted research made it possible to determine a number of positive and negative issues that organizations face when transforming activities. The analysis of digital twins' impact on the optimization of manufacturing processes was carried out.

This paper presents a program that will allow you to design a simulation model of M/D/1 type for queuing systems. In this model the features of multiple access with synchronous-time access to broadcast medium (used for transmitting messages by smart things) were taken into account. These features have a common distribution and there is only 1 service device for them. As a result of the work, the program provides probabilistic-temporal characteristics for analysis according to M/D/1 model, such as: the number of requests in the queue, the average time the request was in the queue, the number of requests left the system and the average time of request in the system in general.

REFERENCES

[1] [1] Astakhova, T., Kolbanev, M., Krasnova, A. Cyber-Physical Systems and Digital Twins as a Concept of Building the World of Intellectual Technologies and Management of Production Processes // Marketing and Smart Technologies. Smart Innovation, Systems and Technologies – vol 280 – Springer, Singapore.

[2] [2] Decree of the President of the Russian Federation No. 203 from May 9, 2017 "On the Strategy for the development of the information society in the Russian Federation for 2017-2030" // [Electronic resource]. - Access mode: http://publication.pravo.gov.ru/Document/View/0001201705100002

[3] [3] Network architecture of the digital economy /N.A. Verzun, M.O. Kolbanev, A.V. Omelyan. – St. Petersburg: Publishing House of St. Petersburg State University, 2018. – 156 p.

[4] [4] Kefeli I. F., Kolbanev M. O., Shamin A. A. Architectural approach to the management of the state program "Digital economy of Russia" // Eurasian integration: economics, law, politics. 2018. No.2 (24).

[5] [5] El Saddik, Abdulmotaleb. "Digital twins: The convergence of multimedia technologies." IEEE multimedia 25.2 (2018): 87-92.

[6] [6] Khajavi, Siavash H., et al. "Digital twin: vision, benefits, boundaries, and creation for buildings." IEEE Access 7 (2019): 147406-147419

[7] [7] Themes Surface in the 2021 Hype Cycle for Emerging Technologies. Access mode: https://www.gartner.com/smarterwithgartner/3-themes-surface-in-the-2021-hype-cy-

cle-for-emerging-technologies
[8] [8] GOST R 57700.37 – 2021. Computer models and simulation. Digital twins of products. General provisions: National Standard of the Russian Federation : effective date 2021-09-06 / Federal Agency for Technical Regulation and Metrology. – Official publication. – Moscow
[9] [9] Astakhova T. N., Kolbanev M. O., Romanova A. A. Smart agricultural field on the basis of the Internet of Things // Regional informatics and information security. Issue No.5. SPOISU. SPb, 2018. Pp. 201–202.
[10] [10] Internet of Things // Recommendation Y.2060. Overview of Internet of Things. ITU-T, Geneva. June 2012.
[11] [11] Verzun N.A., Kolbanev M. O., Romanova A. A., Tsekhanovsky V. V. Evaluation of the energy characteristics of multiple access in terrestrial networks // Izvestiya SPbGETU LETI. 2019. No.10. Pp. 34-38.