Makaruk O.E.

KEY BENEFITS OF USING DIGITAL TWINS IN THE SMART INDUSTRY

Makaruk O.E.

Abstract The process of digital transformation of business processes and business models of industrial enterprises based on the use of digital twin technology have been disclosed in the article. The classification of the main types of industrial digital twins is given, the evaluation of models for the use of digital twins on the level of maturity. An overview of the benefits of using digital twins in the smart industry on the example of the Brest region have been done.

Keywords: smart industry, digital twins, virtual prototype, industry 4.0, process optimization.

Introduction. The rapid acceleration of technological changes is complicating both the final product and production processes, and the increasing rate of changes leads to the rapid ageing of any set of engineering, technical and technological competencies. In turn, the globalization of markets, the ever-increasing global competition, the use of high-tech innovations, the emergence of extremely complex scientific and technical challenges require the industry to accelerate the pace of development, extremely short development cycles, low prices and high quality products. Unlike the previous stages, the industrial transformation being the case in the 21st century affects almost all areas of production, changing its structure and development vectors [16,19].

Today, in order to maintain high labor productivity, economic efficiency and global competitiveness of industry, a necessary condition is the digital transformation of business processes and business models, that is, in fact, transformation into a smart industry based on development and application of digital twins. These phenomena of the Fourth Industrial Revolution fully affect the industry of the Republic of Belarus, formulating the framework conditions for enterprises to operate in the foreseeable future.

Smart industry is an inter-sectoral industrial complex that includes a set of commercial entities of all forms of ownership, whose main activity is industrial production, institutions and subjects of innovative infrastructure that implement and ensure the development, production and marketing of goods using Industry 4.0 elements, namely technological and organizational solutions, including industrial Internet, artificial intelligence technologies, additive technologies, industrial robotics, etc. [17].

The fundamental concept of the Fourth Industrial Revolution is the introduction of cyber-physical systems into factory processes. It is assumed that these systems, aggregated in one network, will communicate with each other in real time, adjust themselves and "learn" new behaviors. Such networks will be able to build production with fewer errors, interact with manufactured goods and, if necessary, adapt to new consumer needs.

Historically, the virtual essence of cyberphysical systems has been defined in many ways: a computational mega-model, a shadow of a physical device, a mirror system, an avatar, a synchronized virtual prototype, etc. [3,4,5]. In the end, the term Digital Twin, DT, established and has become extremely popular recently.

More often Belarusian companies are choosing new technologies of industrial automation and Industry 4.0 as an alternative to expensive technical re-equipment of production, and many design organizations involved in assets development for high-tech industries are technologically and organizationally ready to develop digital counterparts. An innovative breakthrough may ensure the optimal and effective use of technologies for creating digital twins, formulated, as a rule, while working with various industrial companies – world leaders within the international system of division of labor, participation in global technological chains.

Method. The study research uses general scientific methods: historical and logical analysis, generalization, description, classification.

Results and discussion. The creation of digital models by manufacturing companies for the production of new products has been known since the 60s. of the 20th century. This concept originated inside the engineering paradigm applied to industrial products, where there was a clear link of the digital twin with the real object at all stages of the product life cycle. However, at that time, after creating the product, the virtual model was no longer used. In the concept of a digital twin, the virtual model is not discarded after creating a material object, but is used in conjunction with it throughout its entire life cycle: at the stage of testing, completion, operation and disposal.

For the first time, the concept of a digital double was voiced by Michael Grieves [5] in 2002 (Table 1).

Table 1 – Approaches to defining the term "digital twin"

Definition	Source
"each object can be represented as a physical and virtual system, so that a virtual model represents a physical one, and vice versa."	*Grieves M.* Virtually Perfect: Driving Innovative and Lean Products Through Product Lifecycle Management. [5]
"a digital representation of an object sufficient to meet the requirements of a range of use options"	The Industrial Internet of Things consortium. Vocabulary [12]
"a digital model of a specific physical element or process with data connections that provides convergence between physical and virtual states with an appropriate synchronization rate"	ISO 23247 «Digital Twin Framework for Manufacturing» [9]
"a digital (virtual) model of any objects, systems, processes or people. It accurately reproduces the form and actions of the original and is synchronized with it. A digital twin is needed to simulate what will happen to the original in certain conditions"	Pettey, C. Prepare for the Impact of Digital Twins; Gartner: Stamford, CT, USA, [11]
"a system of interconnected highly adequate digital product models, technological, production and operational processes, the parameters of which can be controlled completely in a virtual environment"	Jones D. et al. Characterising the Digital Twin: A systematic literature review, [10]

An important requirement in the digital twin concept is that it must be a dynamic and constantly updated representation of a real physical product, device or process. The static model of real space is not a digital twin (Figure 1).

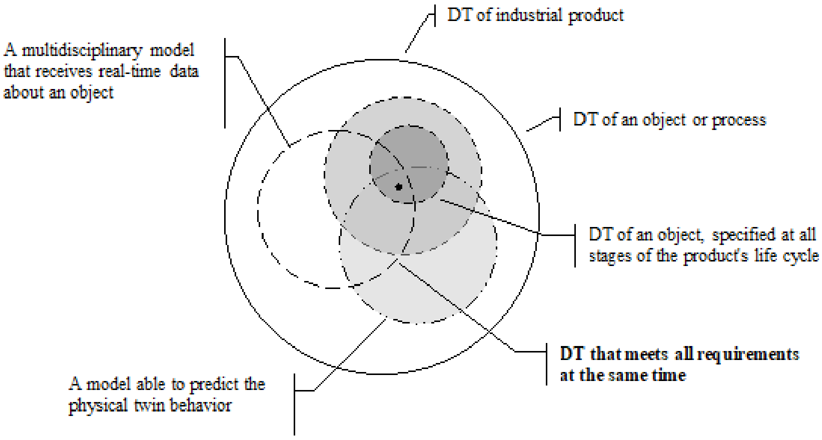

Figure 1 – Boundaries of the digital twin concept in modern publications.

Source: own development based on [19].

The digital twin connects the virtual and physical environment. The physical environment (real object, built-in and external sensors) constantly transmits operation and maintenance data to update the virtual model in a digital twin. Thus, the digital twin becomes an precise representation of the physical system in real time, with any changes to it. The digital twin uses real-time measurement data. This information is supplemented with metadata, properties, and documents, such as reports or work flows, generated at all stages of the object's lifecycle. At different stages, different information and different technologies can be used in digital twins (Figure 2).

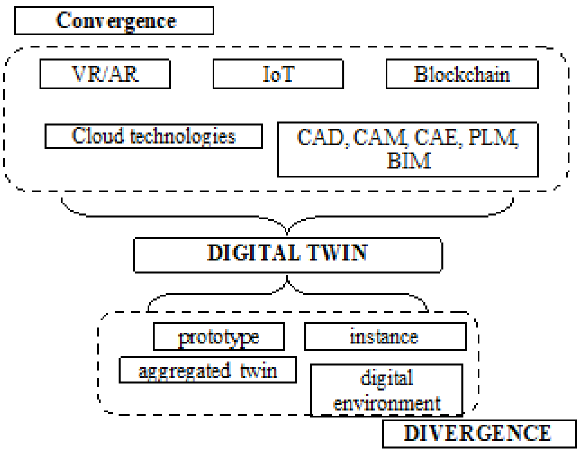

Figure 2 – Convergence and divergence processes in the digital twin concept.

Source: own development based on [1, 2, 19].

The digital twins technology has developed under the influence of convergence processes (involvement of new technologies) and divergence processes (technology application to different groups of users and different industries) [19]. By combining data from different information sources, the digital twin can predict the technical condition of a physical object, as well as can be used to predict the system's response to critical security events. Solutions are possible when the digital twin generates control actions capable of mitigating damage or degradation of systems, activating self-repair mechanisms or recommending changes in the profile of the work mission (e.g., choosing a mode with a lower load on the problem area, thereby increasing both the life expectancy and the probability of mission success).

Multiple versions of digital twins may be divided into 4 categories [20]**:**

– Digital Twin Prototype, DTP, – **a** virtual counterpart of a real physical object. The DTP characterizes the physical object of which it is the prototype, and contains the information required to describe and create a physical version of the object. It contains all data on this product, including that from the design and production stages, for example, product requirements, a 3D-model of the object, a description of technological processes, disposal conditions, etc.

– Digital Twin Instance, DTI –data describing a physical object. For example, an annotated 3D-model, information about materials and components of the product, information about work processes, test results, repair journals, operational data from sensors, monitoring parameters, etc.

– Digital Twin Aggregate, DTA is a system that combines all digital twins and their real prototypes, allowing data to be collected and exchanged in real time.

– Digital Twin Environment, DTE, **is** an application space with several areas for working with digital twins. These operations include predicting performance and requesting information.

In the case of creating a digital twin of a complex object, the process twin creation, in fact, becomes an integral part of digital transformation of this object. Real and virtual spaces are bound, starting from production and operation of the product, device or process itself, and ending with its liquidation. Data from sensors, reports from users and other data obtained in the course of production and operation must be continuously transmitted to the digital twin. In turn, various forecasts and estimates, control parameters and other variables that can be used for the development and operation of a real device must be continuously transmitted back from the virtual space to the real one. It is important to note the possibility of feedback formation [16,19]:

- at the stage of operation - to optimize the process taking into account different operating modes;
- at the production stage - to optimize production processes;
- at the design stage - to re-design critical components or create high-tech New-G products taking into account the experience of operation, maintenance and repairs.

Indeed, the process of building a digital twin implies integration of its elements, creation of digital continuity of the main production process at this facility, which is impossible without moving to the level of the Fourth Industrial Revolution (Table 2).

Table 2 – Digital twins classification by maturity level

Level	The level of model complexity	Physical object	Obtaining data from a physical twin	Machine learning	
				operator preferences	system/ environment
1. Pre-digital twin	Virtual model with a focus on technology / reduction of technical risks	Does not exist	Not applicable	No	No
2. Digital twin	Virtual model of a physical object	Exists	Performance, technical status, maintenance; batch updates	No	No
3. Adaptive digital twin	With an adaptive user interface	Exists	Performance, technical status, maintenance; real-time updates	Yes	No
4. Smart digital twin	With an adaptive user interface and with reinforcement learning	Exists	Performance, technical status, maintenance, environmental information, batch updates and real-time updates	Yes	Yes

Source: own development based on [].

Level 1 Digital Twin. This is a traditional virtual prototype created at the preliminary design stage. It facilitates decision-making when developing a concept and a preliminary project. A virtual prototype is a universal virtual model of a created, anticipated system. Usually such model is created before the physical prototype. Its main purpose is to reduce technical risks and identify problems at the preliminary design stage. Such a virtual prototype can be conditionally called a pre-digital twin.

Level 2 Digital Twin. This is a digital twin in which the virtual model of the system is able to combine data on performance, capacity and maintenance of the physical twin. Data collection from physical sensors and computing elements of the physical twin includes both performance data and technical characteristics. Data are transmitted to the digital twin which updates its model, including the physical system maintenance schedule. A Level 2 digital twin is used to study the behavior of a physical twin in various likely scenarios.

Level 3 Adaptive digital twin. It has an adaptive user interface for physical and digital counterparts. The adaptive user interface is responsive to the preferences and priorities of the user/operator. A key capability at this level is the ability to study operator preferences and priorities in different contexts. Preferred characteristics are recorded using a machine learning algorithm based on neural network technology. Models used in such digital twin are constantly updated based on data received online from the physical twin.

Level 4 Smart digital twin. It features all capabilities of the Level 3 digital twin, including supervised machine learning, but at the same time it has the ability of machine unsupervised learning, thanks to which it recognizes objects and patterns encountered in the working environment. In addition, it supports learning and recognition of system and environment states with reinforcement by signals from the interaction environment in an uncertain, partially observable environment. At this level, the digital twin has a high degree of autonomy.

Thus, a digital twin can be considered as a virtual prototype of a real object or process that contains all data about it, including history and information about the current state. Interactive analysis of this data using Big Data technologies enables effective forecast of future states using predictive analytics, as well as remote online control.

In the Republic of Belarus, the Fourth Industrial Revolution phenomena fully affect all spheres of the economy, including industry, formulating the framework conditions in which enterprises will operate in the foreseeable future. To date, Belarusian industrial enterprises are still solving issues related to the creation of basic conditions for Industry 4.0, often mistakenly believing that Industry 4.0 is limited to digitalization or full automation. Digital technologies based on hardware and software are not an innovation in themselves, but combining into global networks, constantly improving, integrating into new and new spheres of human life, they are steadily transforming the global economy, moving further away from the level of the Third Industrial Revolution [15].

Following the Program of socio-economic development of the Republic of Belarus for 2021-2025 approved by Presidential Decree No. 292 of 07/29/2021, one of the objectives facing industrial enterprises will be the introduction of information and communication technologies and advanced production technologies based on the principles of the Industry 4.0 concept, the smart industry development [19].

The Brest Region is actively working to promote Industry 4.0 technologies. By Resolution No. 623 of October 30, 2020, the Council of Ministers approved the international technical assistance project "Stimulating the potential of technologies of the Fourth Industrial Revolution for inclusive and sustainable industrial development in Belarus", a unique project to be implemented by the Ministry of Economy together with the United Nations Industrial Development Organization (UNIDO) on the basis of the Brest Science and Technology Park. Creating the Brest Demonstration and Innovation Center for Industry 4.0 Technologies will promote technological training in smart manufacturing and innovation for small and medium-sized enterprises, promoting effective interaction between national and regional government bodies, industry and academia, stimulating the development of regional innovation systems and business ecosystems.

For the effective operation of the Brest Demonstration and Innovation Center for Industry 4.0 technologies, it is planned to purchase modern equipment: a 3D printer and scanners for prototyping products and digital models, a robotic arm for software and production experiments, equipment for experiments with unmanned driving, drones, sensors and meters for testing and piloting new business models, etc. [15].

At present, smart industry technologies in Brest Oblast are most widely represented at the food industry enterprises of the region. The food industry development is directly influenced by many special factors, including legal regulation and social trends. Requirements for the production process are constantly growing: sanitary and hygienic standards are becoming stricter, consumer demand and preferences are changing faster than ever. An effective solution is the use of digital twins, which significantly reduces organizational costs and reduces the time for a new site, project, and launch of a new product, since the entire preparatory part is transferred to the modeling environment and worked out there.

In 2020, the Industrial Robotics Laboratory started operating in Brest, the founders of which were Brest State Technical University, Industrial Automation Systems LLC and Savushkin Product OJSC. A separate area of the workflow is devoted specifically to digital modeling, when project development is implemented on the basis of an exact digital copy of the equipment, which is then delivered to the enterprise. Enterprises can calculate and verify the upcoming changes of production lines in the software environment. Creating digital twins may go using various technologies, depending on whether a twin is being created for future production, and on what stage of design this production facility is, or it is being created for an existing production, as well as depending on the purpose of the created twin and the degree of detail required from the simulation model. Thus, customers save on the fact that they almost completely eliminate errors during production restructuring: with the right approach, everything has already been calibrated through digital engineering. Moreover, it is now possible to make many changes practically without stopping real production [17].

A virtual model can be built for the entire factory shop or its individual parts. With its help, engineers can test various equipment settings, changing them until the result is the best. And only then introduce innovations into reality.

Introducing digital twins into production provides industrial enterprises with an opportunity to predict the results of too expensive or complex changes using virtual sensors, test "what if...?" scenarios for changes in production processes, as well as optimize production at the design stage and compare optimal performance with actual one.

Digital engineering gives the greatest advantage to enterprises that actively use robots and automated equipment or strive for their implementation. This is due to the fact that modern software provides an opportunity to fully test and debug the operation of these components in a virtual environment in a short time. The Industrial Robotics Laboratory actively cooperates with such global brands as Techman Robot (a manufacturer of collaborative robots), OnRobot (advanced gripping systems and sensors for industrial automation), Robotize (mobile robotics), Visual Components (a leading developer of software and solutions for 3D modeling of production), Festo (pneumatic automation and automation), etc.

Thus, the use of digital twins technology in smart industry enables enterprises to achieve the following advantages:

1. Having this model, it is possible to verify the product compliance with marketing statements or regulatory requirements. The twin makes it possible to quickly transform the production technology to transfer production between factories and adapt them to new equipment.

2. Optimized conveyor operation. One of the tasks of food industry enterprises is to organize production lines so that they are flexible, while occupying a smaller area and maintaining high throughput. Visualization of belts and conveyors through digital twins helps to develop customized solutions for clients so that they can immediately see how the technology will improve the flow of products at their enterprise, as well as run several possible scenarios at once to choose the optimal one.

3. Supplies quality control. Food industry enterprises often work with a large number of very diverse suppliers, so supply chains transparency is both an important and challenging task. Thanks to digital twins, manufacturers can observe online what is happening to their products at each production stage. For example, using sensors, it is possible to determine whether products have been exposed to temperatures or other environmental conditions that may make them dangerous to consume. Such information allows enterprises to prevent defects in production and choose reliable suppliers.

4. Orchestration of the entire process of dispatching and servicing of equipment, i.e. linking with existing production and service systems at the enterprise. This issue is also relevant for many enterprises, because today Industry 4.0 no longer implies patchwork technologies, but integrated solutions built into the existing control circuit. In addition, the system model has a built-in optimization module which makes it possible to build technological modes based on complex technical and economic target functions.

The presence of a dynamic model also helps to combine the developments created in the design organization and the developments existing at the equipment manufacturer, and transfer this data directly into operation.

It is important to note that digital twins also involve machine learning technologies since they are, in fact, self-learning systems that use information from a number of sources, including data from sensors monitoring various working parameters of the physical object, information from expert specialists and other similar machines or fleets of machines, as well as larger systems, of which the observed physical object may be a part.

Conclusion. Digital twins in industrial enterprises are able to increase their efficiency, reducing costs and increasing the operational reliability of equipment, since they are based on numerical and system modeling technologies widely used in the industry.

The digital economy leads to the accelerated introduction of fundamentally new business models. There is an opportunity to create a competitive economy based on technical means driven by smart industry. Enterprises are integrated into global industrial networks to combine a network of production resources and global applications. Modernizing the manufacturing sector will allow introduction of new technologies into Belarusian industry – smart industry (smart production), which will become a key factor in increasing products competitiveness.

Introducing information and communication technologies and advanced manufacturing technologies based on Industry 4.0 concept principles allows to exempt the manufacturer from the need to implement long-term and expensive field tests in the course of project implementation, quickly redesign products to meet certain requirements, minimize the number of calculation errors (including those related to the human factor), makes it possible to increase the percentage of localization and, as a result, remove the dependence of manufacturers on foreign orders while meeting the highest requirements for technological, user operational and other indicators.

References

1. Digital Twins for Industrial Applications: Definition, business values, design aspects, standards and use cases. An Industrial Internet Consortium White Paper // Industrial Internet Consortium. – Mode of access: https://iiconsortium.org/pdf/IIC_Digital_Twins_Industrial_Apps_White_Paper_2020-02-18.pdf. – Date of access : 16.09.2021.

2. GE Power Digital Solutions (2016). GE Digital Twin // General Electric – Mode of access: https://www.ge.com/sites/default/files/GE_Power_120116_1.pdf – Date of access : 16.09.2021.

3. Glaessgen, E. H.; Stargel, D. S. The Digital Twin Paradigm for Future NASA and U.S. Air Force Vehicles. In 53rd Struct. Dyn. Mater. Conf. Special Session: Digital Twin, Honolulu, HI, US., 2012.

4. Götz M., Jankowska B. Adoption of Industry 4.0 Technologies and Company Competitiveness: Case Studies from a Post-Transition Economy.– 2020. – Foresight and STI Governance, vol. 14, no 4, pp. 61–78.

5. Grieves M. Virtually Perfect: Driving Innovative and Lean Products Through Product Lifecycle Management. Cocoa Beach - FL, USA: Space Coast Press. 2011.

6. Grieves, M. Digital Twin: Manufacturing Excellence through Virtual Factory Replication; A White Paper; Michael Grieves, LLC: Melbourne, FL, USA, 2014.

7. Маковельский, О.А., Есаулов А.Б. Фабрика Цифровой Трансформации: «Сегодня Индустрия 4.0 – это уже не лоскутные технологии, а интегрированные решения // журнал «Neftegaz.RU» №9(105) 2020. – с. 46-50.

8. Industry 4.0: Building the digital enterprise, 2016 Global Industry 4.0 Survey // PWC. – Mode of access: https://www.pwc.com/gx/en/industries/industries-4.0/landing-page/industry-4.0-building-your-digital- enterprise-april-2016.pdf – Date of access : 16.09.2021.

9. ISO 23247 «Digital Twin Framework for Manufacturing» // International Organization for Standardization – Mode of access: https://www.iso.org/standard/75066.html – Date of access : 16.09.2021.

10. Jones D. et al. Characterising the Digital Twin: A systematic literature review // CIRP Journal of Manufacturing Science and Technology. – Mode of access: https://www.journals.elsevier.com/cirp-journal-of-manufacturing-science-and-technology – Date of access : 16.09.2021.

11. Pettey, C. Prepare for the Impact of Digital Twins; Gartner: Stamford, CT, USA, 2017.

12. The Industrial Internet of Things consortium. Vocabulary // The Industry IoT Consortium – Mode of access: – Mode of access: – Date of access : 16.09.2021.

13. The New Age of Manufacturing: Digital Twin Technology & IoT – Mode of access: https://www.seebo.com/digitaltwin-technology. – Date of access : 16.09.2021.

14. Зазерская, В. В. Факторы устойчивого экономического роста в условиях цифровой экономики / В. В. Зазерская // Вестник Брестского государственного технического университета. Серия: Экономика. – 2020. – № 3. – С. 27–29.

15. Макарук, О.Е. Внедрение технологий Индустрии 4.0 в деятельность субъектов инновационной деятельности Брестской области /О.Е. Макарук//Инжиниринг и управление: от теории к практике: сборник материалов XVIII Международной научно-практической конференции, 15 апреля 2021 г./Белорусский национальный технический университет; редкол.: С.Ю. Солодовников (пред. редкол.)[и др.].–Минск: БНТУ, 2021.–С. 207-208.

16. Ковалев, М. М. Цифровая экономика – шанс для Беларуси: моногр. / М. М. Ковалев, Г. Г. Головенчик. – Минск: Изд. центр. БГУ, 2018. – 327 с.

17. Лаборатория робототехники БрГТУ – Mode of access: https://robotics.bstu.by/. – Date of access : 16.09.2021.

18. О Государственной программе «Цифровое развитие Беларуси» на 2021–2025 годы, утв. Постановлением Совета Министров Республики Беларусь от 2 февраля 2021 г. № 66.

19. Программа социально-экономического развития Республики Беларусь на 2021– 2025 годы, утв. Указом Президента Республики Беларусь от 29.07.2021 № 292.

20. Прохоров А., Лысачев М. Научный редактор профессор Боровков А. Цифровой двойник. Анализ, тренды, мировой опыт. Издание первое, исправленное и дополненное. – М.: ООО «АльянсПринт», 2020. – 401 с.

21. Хитрых, Д.А. Цифровой двойник: концепция, уровни, связь с Интернетом вещей и роль численного и системного моделирования // «САПР и Графика. Спецвыпуск». – с. 8-12.

22. Шумилин, А.Г. «Смарт-индустрия» станет ключевым фактором роста конкурентоспособности // международный форум по внедрению умных технологий в реальный сектор экономики Smart Industry Expo (SIEx) – Mode of access: https://smartexpo.pro/siex2020. – Date of access : 16.09.2021.