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Characteristics of the use of digital twins by industrial enterprises: the experience of foreign countries and Kazakhstan

Abstract

Object: digital twins, adapted to the tasks of industrial companies.

Methods: content analysis for the purpose of organizing and structuring the main scientific research related to the study of the use of digital twins, their role and importance for industrial companies; the analysis method that allowed to evaluate the current state of digitalization of production processes in companies; a graphic interpretation method that allowed to visualize the obtained results.

Findings: the concept of “digital twin” is considered and the aspects of its application in the sphere of industrial production are analyzed on the example of foreign companies and enterprises of Kazakhstan; the tasks of digital twins and the advantages of their implementation in production are pointed out; the stages of building digital twins were studied.

Conclusions: the study showed that the use of digital twins opens up new opportunities to improve the efficiency and competitiveness of an industrial company. The results provided an opportunity to assess the annually growing interest in the technology of digital twin; based on the analyzed sources, successful examples of the implementation of digital twins in the activities of industrial enterprises of foreign countries and Kazakhstan are considered.

Keywords: production process, digital technologies, digital twin, virtual product, cyberspace, components of the digital twin.

Introduction

The issue of transition to high-tech industries in the context of global competition is especially relevant in recent decades and reveals in practice in increasing the level of automation of enterprises and in the widespread digitalization of production processes. There is a need for fast and accurate modeling of products and their production technology to save resources and increase the profitability of production in modern conditions, where consumer demand for customized products is significantly increasing.

Thanks to Industry 4.0, the storage of all data in digital form and the sensors installed in industrial spaces, the implementation of digital twins became possible. With the proliferation of the Industrial Internet of Things (IIoT), digital twin technology has gained widespread importance. Moreover, with the advent of comprehensive modeling capabilities and a significant increase in computational resources, it has become possible to perform realistic testing in a virtual environment.

The article aims to study the main aspects of the application of digital twins by industrial enterprises abroad and in Kazakhstan.

The following tasks are defined: the study of the essence of digital twins from the point of view of the analysis of the research work of modern scientists; the consideration of the main stages of the construction of digital twins in industrial production; the identification of the advantages and limitations of the use of digital twins in manufacturing enterprises.

The working hypothesis of the study is the assumption that the interest of both the scientific community and the management of enterprises in the essence and applicability of the technology of digital twins in practice, as well as in determining their economic efficiency and feasibility of implementation for the creation of innovative products with high added value and a pronounced customer-specific component, is increasing year by year.

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A digital twin is a digital copy of a specific physical object that reflects the structure, performance, technical condition, and type of work mission of a physical object, including parameters such as miles traveled, malfunctions, and maintenance and repair history of a real product (physical twin).

The concept of the digital twin was first described in 2002 by Michael Greaves, a professor at the University of Michigan. In his book The "Origin of Digital Twins", he divided it into three main components: 1) the physical product in real space; 2) a virtual product in a virtual space; 3) data and information connecting a virtual and a physical product.

Tao F., Zhang H., Liu A., Nee A.Y. also identify VV &A (verification, validation, and accreditation) as components of digital twins and assert that "digital twins are characterized by seamless integration between cyber and physical spaces" (Fig. 1).

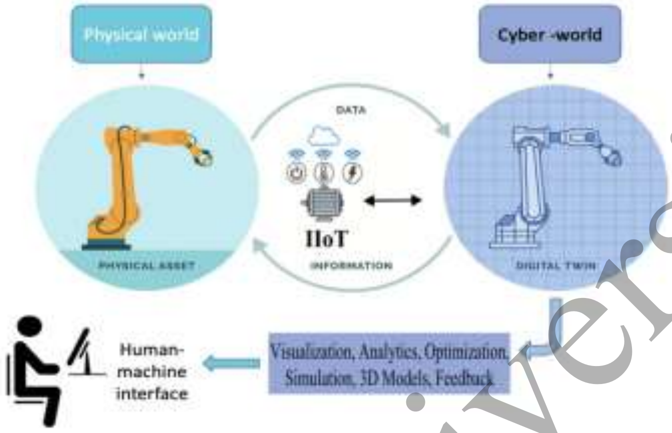

Figure 1. Illustration of IIoT, cyber-physical systems and digital twins in the physical and virtual world

Note – compiled by the authors.

However, in 2002, the idea was not yet widely supported, largely due to the technical imperfection of the technologies of that period:

– most data was stored in paper form and processed manually;

– receiving and storing a stream of various data about a product or technological process in real time was practically unfeasible;

– there was no suitable hardware and software.

In 2011, NASA first gave a specific concept for digital twins and applied it to the maintenance and protection of future spacecraft. Specifically, a model was created in digital space. Sensors were then used to achieve full synchronization with the actual state of the ship, and historical data was analyzed to assess maintenance needs. Digital twin (DT) technology is not limited to the aerospace industry, but extends to other fields, such as production planning and linear design, production process optimization, healthcare prediction and management, and the smart city concept.

Literature Review

In the scientific world, there is not yet a unified approach to understanding and interpreting digital twins, as digital twin technology and the solutions based on it are still at an early stage of development, the professional community has not yet developed generally accepted definitions and standards, and experts argue about what a digital twin is, what types of DT exist, in which industry solutions this term is applicable, etc.

Among the sources that reveal theoretical approaches to understanding the nature of the "digital twin" are the works of Grieves M., Tao F., Savolainen J., Gao C., Ghosh A., Jones D., Kajba M., Boyes H., Singha S., Wang Y., Haoa B. (Grieves M., Vickers, J., 2017; Tao F. et al., 2019; Jones D. et al., 2020; Ghosh A. et al., 2021; Savolainen J., Knudsen M., 2021; Singha S. et al., 2021; Boyes H., Watson T., 2022; Gao C. et al., 2022; Haoa B., Yulib W., 2022; Kajba M. 2022; Wang Y. et al, 2022). For example, in the publication "Digital Twin: Mitigating Unpredictable, Undesirable Emergent Behavior in Complex Systems", Grieves M. suggests that the idea of a digital twin, which connects a physical system to its virtual equivalent, could mitigate problematic issues related to human interaction. The author describes the concept of the digital twin and its evolution and shows how it is used throughout the product life cycle to determine and understand system behavior.

Boyes H., Watson T. in their study "Digital twins: An analysis framework and open issues" propose a research methodology to compare the characteristics of all digital twins with this structure and characterize or compare two or more digital twins. By creating a structure that contains the common functional characteristics of the sixteen functional components of a digital twin, the authors sought to reduce the confusion caused by the multitude of definitions of digital twins and their interpretation by suppliers.

In the paper "A Survey of Digital Twin Techniques in Smart Manufacturing and Management of Energy Applications" Wang Y. et al systematically review existing approaches to digital twins and their potential applications in the energy domain. The benefits of digital twins and related technological innovations for smart grids can be summarized as follows: optimizing grid energy consumption; monitoring irregular power consumption; reducing carbon emissions and monitoring them in real-time.

However, the application of digital twin technology in the industry has not only advantages, but also encounters certain difficulties (Jiang Y. et al, 2021; Mincă E. et al., 2022; Sharma A. et al., 2022; Zeb Sh. et al., 2022). In the publication "Digital Twins: State of the art theory and practice, challenges, and open research questions" Sharma A. et al explored that depending on technologies such as IoT, Big Data, and machine learning, there may be a large gap between the ideal implementation of DT and practical implementation (e.g., whether the required technology development is currently available, whether the company has significant resources, finances, and specialists to implement a practical digital twin in production).

Digital twins are the most complex models that describe the structure, context and behavior of both individual industrial assets and the systems that comprise them (Priyanka E., et al, 2021; Wang P., Luo M., 2021; Fonseca A., et al, 2022; Lehtola V. et al, 2022; Paolone G., et al, 2022; Thürera M., et al., 2022; Valka H. et al., 2022; Zhang R. et al., 2022; Xiang F. et al, 2022). For example, Zambrano V. et al., 2022 in their work "Industrial digitalization in the industry 4.0 era: Classification, reuse and authoring of digital models on Digital Twin platforms" describe the support of the modular design of digital twins through the reuse of their basic building blocks, i.e., the models describing the behavior of the DT, the algorithms associated with them, and the data required for their evaluation. How digital models can be classified, reused, and created on such digital twin platforms is explored and validated through an experimental analysis of three industrial use cases of DT.

Of particular note is M. Kajba's study of the amount of published literature on the use of digital twins in manufacturing, logistics, and supply chains, based on analysis of data from the "Web of Science" scientometric database. The study includes data on search results for keywords for the period from 2018 to 2021. The main keyword received 125 searches in 2018. To the latter, the search query "production" was added and the number of queries fell sharply to 21, which is 16.8%. When the keyword "manufacturing" was replaced by "supply chain", only 1 request was received, which is 0.8% of the total.

As seen below in Figures 2 and 3, the largest number of search results were found for articles called "digital twin". It can be argued that the number of articles about digital twins has doubled compared to the previous year.

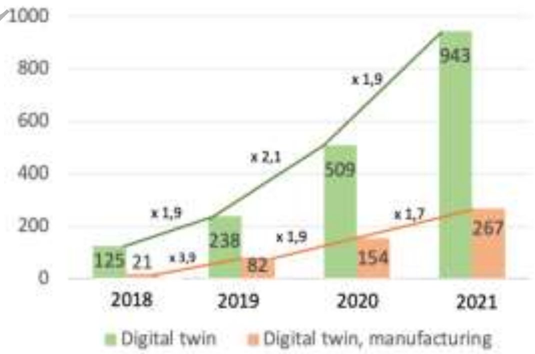

Figure 2. The number of articles about digital twins for 2018-2021

Note – compiled by the authors on the basis of the source (Kajba M., 2022)

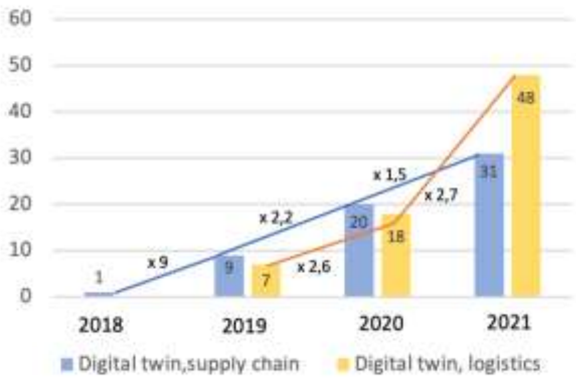

Figure 3. The number of articles about digital twins in logistics for 2018-2021

Note – compiled by the authors on the basis of the source (Kajba M., 2022)

Then, another keyword, “manufacturing” was included. In 2019, the number of articles about the “digital twin” and “production” increased 3.9 times compared to the previous year: from 21 to 82 articles. In 2020, the number of articles was 1.9 times higher than a year earlier and amounted to 154. In 2021, this number increased by 1.7 times, amounting to 267 published scientific papers.

Digital twins and related technologies are a popular research topic (among academics, professionals, IT specialists, as well as ordinary users interested in technology), as shown by the analysis of Google Trends-based searches for the keywords “digital twin” for the period February 2018 to February 2023. The number of queries increased fivefold from 18 to 100 (Fig. 4).

Figure 4. The number of requests on the digital twins topic for February 2018-2023.

Note – compiled by the authors based on GoogleTrends data

The highest level of interest in the topic of digital twins was noted in China, Singapore, Korea, Hong Kong, Norway, the United Arab Emirates, Finland, Switzerland, Austria, and Italy.

Methods:

The following research methods were used in the paper: *the content analysis method* to organize and structure the main scientific research related to the study of the use of digital twins, their role and importance for industrial companies. Within the framework of this method, literature sources published in the scientific databases Scopus, Web of Science, RSCI were used; *the analysis method* that allowed to evaluate the current state of digitalization of production processes in industrial companies; *a graphical interpretation method* that allowed to visualize the obtained results.

Results:

The concept of the digital twin is gaining interest in both research and industrial contexts, and is included in the list of key strategic technology trends in many countries around the world. In addition, more and more organizations and companies are recognizing the value of digital twins and investing numerous resources in exploring the possibilities of their potential application. Major logistics service providers such as DHL see digital twins as a promising technology trend.

The global market for digital twins was estimated to reach 3.1 billion US dollars by the end of 2020. According to the forecast of the analytical agency Markets and Markets, the market for digital twins will reach 48.2 billion US dollars by 2026. According to analysts, spending on digital twin projects will increase by an average of 58% per year (Fig. 5).

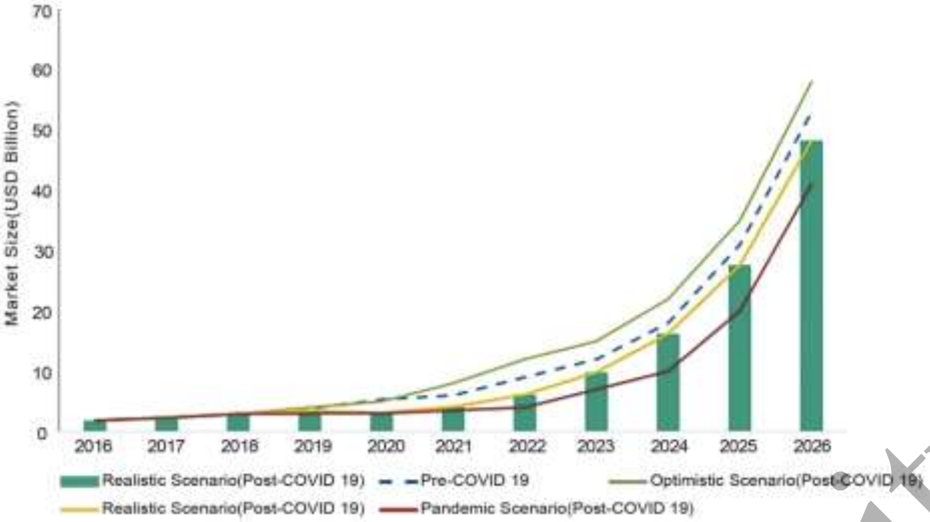

Figure 5. Forecast of growth in the market of digital twins

Note – compiled by the authors on the basis of the sourcewww.tadviser.ru

Manufacturing production processes and shop floor design are more closely integrated through digital twins. Simultaneous display and real-time interaction between physical and virtual equipment enable rapid detection of faults, which in turn provides opportunities for streamlining a maintenance strategy. Industrial production uses digital twins — virtual copies of the finished product; equipment and devices; the production process or the entire enterprise.

In September 2021, Russia became the first country in the world to adopt standards in the field of digital twins. The corresponding document, which was approved by Rosstandart and came into force on January 1, 2022, was entitled "Numerical modeling" — GOST P 57700.37–2021 "Computer models and modeling. Digital twins of products. General". The national standard is the first in a series of national and industry regulatory technical documents that will determine the procedure for developing digital twins, standard requirements for the structure and procedure for their support during the product operation, the procedure for accounting and storage, etc.

For the first time in world practice, a single definition of the digital twin of the product is established — "this is a system consisting of a digital model of the product and bilateral information links with the product (if the product is existing) and (or) its component parts".

This standard was developed by a working group under the leadership of the NTI Competence Center "New Production Technologies" of the Peter the Great St. Petersburg Polytechnic University and the Federal State Unitary Enterprise "Russian Federal Nuclear Center — All-Russian Research Institute of Experimental Physics" as part of the activities of technical committee No. 700 "Mathematical modeling and high-performance computing technologies" (TC 700).

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

Experts consider the optimal error between the operation of the digital twin and its physical prototype to be no more than 5%. This criterion is met by aggregated doubles of the Digital Twin Aggregate level. These are dynamic computational models that allow not only to collect operational data from sensors, but also to exchange this information with other systems that control technological processes.

The components of the digital twin include elementary and imperative components (Fig. 6). Without the elementary components, the digital twin cannot exist. Imperative components complement the properties of digital twins, making it a comprehensive modeling, real-time monitoring, and analytics tool. Without them, the uniqueness of digital twins ceases to exist. The existence of each of these components depends to a large extent on the subject area and application of digital twins.

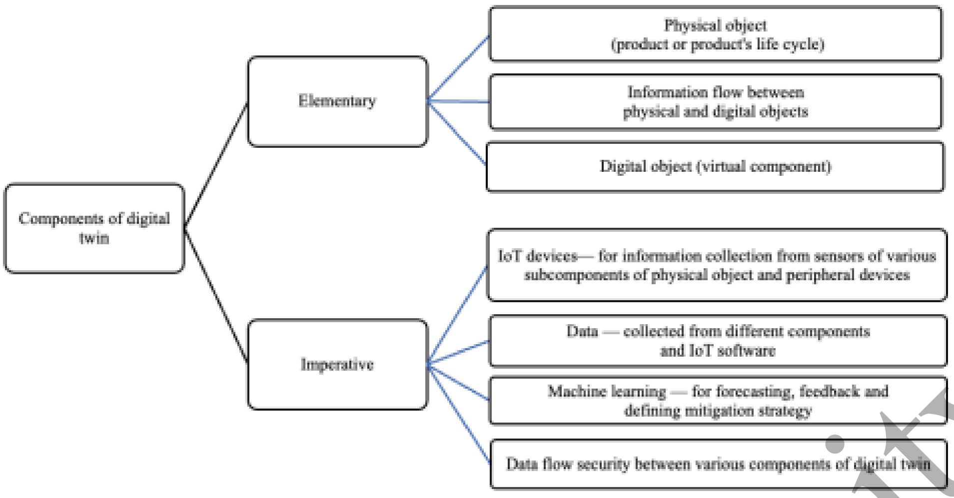

Figure 6. Components of digital twin

Note – compiled by the authors

The digital twin provides feedback and interoperability of physical objects through interactive feedback, data aggregation and analysis, and optimization of solutions for efficient management, security monitoring, and data analysis. The digital twin acts as a digital advisor, analyzes the existing technological process, allows to identify bottlenecks in the production process and helps to implement the strategy for the development of the production process. Figure 7 below shows the tasks for digital twins.

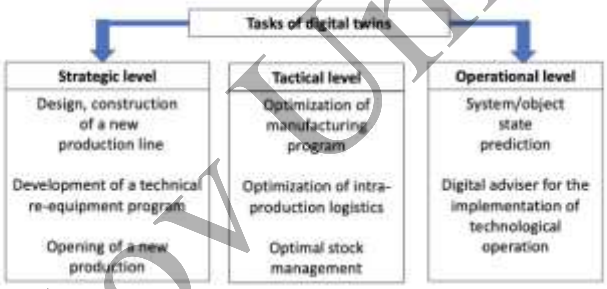

Figure 7. Tasks for digital twins

Note – compiled by the authors on the basis of the source bia-tech.ru

The use of digital twins in production allows for uncertainty management. Within the framework of the DT, different levels of production intensity, incoming orders for production are set. It becomes possible to conduct various kinds of stress testing, the formation of a hypothetical situation. The use of the DT allows to expand the boundaries of uncertainty assessment.

The digital twin also allows the company to experiment in a risk-free environment. The virtual model exactly repeats the real physical process. Simulation of changes in production is tested in a virtual environment, without stopping production processes, the calculation of the optimal volume of production resources is carried out.

It becomes possible to test a large number of hypotheses and exclude activities that do not bring an economic effect. In turn, pre-tested and proven hypotheses will allow the company to reduce costs. The digital model makes it possible to test hypotheses, get calculations in an accelerated mode and find out in 5 minutes what will happen to a physical object in a week or a month.

The stages of digital twin construction are shown in Fig. 8.

Digital models for the production of new products at the enterprises have been used for a long time. But previously, in most cases, after receiving the finished product, the virtual model was sent to the archive. In the concept of a “digital twin”, the virtual model is not discarded after the creation of the product, but is used in conjunction with its physical twin throughout the life cycle: at the stages of testing, refinement, operation and disposal.

This allows to create channels of valuable feedback. Thanks to the receipt of information from sensors installed on technological equipment, in workshops, transportation facilities, the digital twin in real time builds an up-to-date model of the production system in the digital environment. This operation is the prerogative of the operational model of the digital twin of the production system. As a result, authorized employees receive comprehensive information about such parameters as equipment loading, its depreciation, temperature in the shop and in the areas of direct processing, production operations and their parameters performed at the moment, the amount of raw materials in the warehouse, etc.

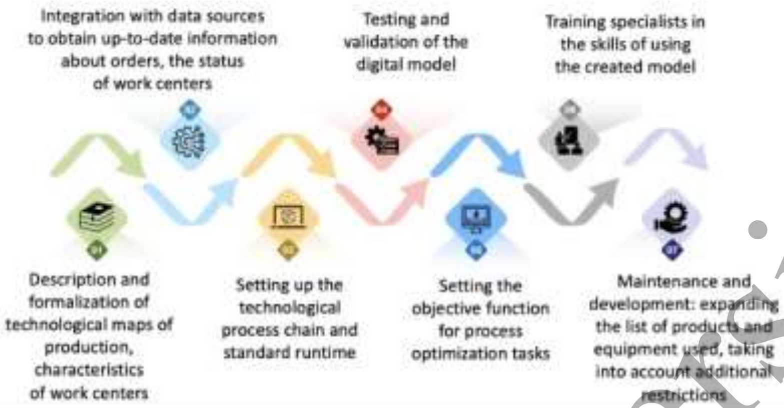

Figure 8. The stages of digital twin construction

Note – compiled by the authors on the basis of source bia-tech.ru/

A digital twin can significantly increase the stability of the operation or functioning of a real object — equipment, product or component of the production cycle. For example, Shnaider Electric specialists with the help of a digital twin and predictive analytics managed to predict a compressor failure at an oil refinery 25 days before it could actually happen, which saved the company several million US dollars.

Companies such as Siemens, General Electric, IBM, Microsoft and Bosch today already offer the concept of digital twins as a service for enterprises. For example, General Electric offers a digital twin platform that allows predicting the behavior of the system in advance, and Siemens is focused on smart processes of product development. There are several successful examples of the transition to Industry 4.0 using the concept of “digital twins” (Table).

Table. Application of digital twins by foreign industrial enterprises and companies of Kazakhstan

Company name	Description of the used digital twin	Expected efficiency from use
General Electric, USA	Digital twin called “Trip Optimizer” of the locomotive “Evolution 89 series”	- optimization of the trip (optimal speeds and fuel consumption levels are calculated) based on the available schedule and data on the state of the rolling stock traction engine, weather conditions, etc; - savings of 8-10% on fuel and reduction of emissions by 174 thousand tons per year.
General Electric Research, USA	Digital twin of the wind turbine logistics process	- accurate forecasting and optimization of logistics costs. Based on the current industry forecast, a 10% reduction in logistics costs is possible, representing global cost savings for the wind energy sector of up to 2.6 billion US dollars per year by 2030.
Tesla, USA	Digital twin of electric vehicles	- tracking the working condition of the electric vehicle; - identification of the problem at an early stage in order to avoid costly repairs; - ensuring the best service and reliability of each copy of the electric vehicle.
Goldcorp, Canada	ANDRITZ digital twin for managing gold mining operations (as well as other precious metals)	-analysis of data received from sensors and equipment at the production site and prediction of possible problems; - recommended solutions based on sensor data to optimize plant-wide operations.

Suncor Energy, Canada	Digital twins for process control in the oil and gas industry	- management of production processes, such as oil and gas production - forecasting and elimination of possible problems
Petrobras, Brazil	Digital twins of oil and gas fields	- modeling of its oil fields and optimization of production processes
Embraer, Brazil	Digital twin from GE Aviation, using its Predix software suite, which provides an integrated platform for storing, analyzing and modeling digital twins	-design and development of aircraft; - optimization of production processes; - the ability for analysts to determine correlations between variables, as well as faster to understand, predict and optimize the performance of an engine or aircraft.
Maserati, Italy	Ghibli digital twin based on Siemens NX, Tecnomatix, SIMATIC IT MES and TIA Portaltechnologies	Control of the production process of the Maserati Ghibli model: - development of vehicle components; modeling of production processes; - design of automation processes; planning and optimization of production processes; - reduction of costs and reduction of vehicle development time by 30%.
CNH Industrial, Italy	Digital twin on the welding line of the chassis of the Iveco van truck	- predicting the probability of failure of critical components, running the script "What if?"; - comparison of different operating and maintenance modes to optimize maintenance costs and spare parts; — minimization of planned and unplanned downtime.
KLM Royal Dutch Airlines, Netherlands	Airliner Digital Twins for Online Learning	- reducing the carbon footprint and costs with the help of multiple versions of digital twins of airliners for virtual training purposes, - reduced operational impact thanks to instant mobile access to digital twins during pre-flight pilot tours.
Volkswagen, Germany	Digital Twin of the car: digital 3D prototypes of different car models, such as the Golf	- providing employees of the company in different countries of the world with detailed model data in real-time; - the use of digital tools in combination with augmented reality, which allows to view and change digital twins using gestures and voice commands.
Alstom, France	Digital twin to support decision-making in the field of train maintenance	- optimization of the planning of maintenance of trains, including tasks such as estimation of the required number of trains, their route, modes (frequency of maintenance, unscheduled maintenance in case of breakdowns, etc.).
Peugeot (PSA Group); France	Digital twin of the car	- Reduction of production costs up to 50% due to the replacement of physical work with digital twins on test benches.
PJSC "T Plus", Russia	"EMAS.OPT, EMAS.TEP"	- optimization of boilers for three types of fuel: coal, gas and fuel oil; - calculation of planned values of technical and economic indicators based on the results of solving the optimization problem; - a single database of characteristics of the entire fleet of main equipment, on the basis of which it is possible to find and further make changes to any consumption characteristic.
OJSC "TGK-16", Russia	"EMAS.OPT" Kazan CHPP-3 model implemented	- planning the optimal operating modes of the station using a solution based on the use of the mixed integer linear programming method.

Uralmash zavod, Russia	Digital twin (DT-1): vibrating sieve for drilling fluid cleaning system	- a fundamentally new design of the vibrating sieve for the drilling rig was developed, which made it possible to significantly surpass the performance of the product in comparison with competitors; - significantly improved the main characteristics of the design: the overload coefficient is increased to 8.8 g, the weight is reduced.
Gazprom neft, Russia	Digital Twin Seismic exploration: Innovative system of planning and monitoring of geological exploration	- provides the company's specialists with prompt remote access to summary statistics and data of search projects to obtain up-to-date geophysical information; - includes modules of predictive and video analytics, risk analysis, recommendations and mapping operations; - huge arrays of geological exploration data have been systematized, the accuracy has been increased and the cost of prospecting projects has been reduced.
Haier, China	Digital twin of production process	-improvement of the process of design, testing and optimization of production.
China National Petroleum Corporation (CNPC), China	Digital twin of oil/gas field	- simulation of oil and gas fields, improving productivity and reducing costs
HeroMotoCorp, India	Digital twin of production equipment using the 3D EXPERIENCE platform from Dassault Systèmes	- standardization of production processes; — creation of a single data repository; - optimization of time and material costs; - assessment of the manufacturability of new models of vehicles; - identification of problems before the start of production and timely corrective actions.
National Thermal Power Corporation, India	Digital twin of energy systems	- power system management and optimization of production processes.
Wood side Energy, Australia	Digital twin of equipment	- management of oil and gas facilities; - reduced equipment downtime and increased productivity.
“Kazakhmys”, Kazakhstan	Digital twin of the mines	- management of mining processes; - analysis of data received from sensors and equipment at the production sites, forecasting possible problems.
JSC “Shubarkul Premium”, Kazakhstan	Digital twin of section	- online mode of monitoring the load on various machinery, equipment; - monitoring of fuel consumption; - automated supply, maintenance and repair; - fully digitalized document flow.
LTD “Water resources -Marketing”, Kazakhstan	Digital twin of the water supply and sewerage system of the city of Shymkent	- the ability to calculate the necessary load on water supply networks; - reduction of accidents; - acceleration of emergency recovery work time.
Gold mining plant “Altyn almas”, Kazakhstan	“Digital mine”	- reduction of the amount of necessary materials by 15% and elimination of collisions during the construction phase; - Bentley's open 3D and 4D modeling applications and Digital Twin technology allowed the company to perform design and construction work simultaneously, resulting in the factory being put into operation 30% of the time ahead of schedule.

Note – compiled by the authors on the basis of company data

The use of digital twins helps to significantly reduce the time to market entry of new products, provides transparency of the production process and provides the company's management with real levers for management and optimization. The use of digital twins leads to an increase in production efficiency due to high operational flexibility by 5-7%, a reduction in working capital by 30-50%, a reduction in the average lead time for orders up to 20%, an increase in labor productivity by 15-30%.

Currently, digital twin models face the following challenges, depending on the field where digital twins are being implemented. These problems are mainly of a technical nature:

– high-precision 2-way synchronization is especially difficult for large industries, requires resources and high-stream connection to implement IoT tasks;

– compatibility with existing software used in the production cycle for tasks such as inventory, product management and operations. Solving the compatibility problem can lead to a delay in the implementation of the DT;

– problems of cybersecurity, security of cross-industrial partners;

– additional resources: the use of digital twins requires the investment of certain resources, finances and research.

In the coming years, large companies will move to remote monitoring and management of entire production and all departments through virtual systems. The same will happen with cities: they will acquire digital twins that unite all the most important systems, districts and urban infrastructure. Online monitoring will be carried out using IoT sensors, scanners and drones with machine learning, and the virtual systems themselves will be placed in the cloud. This will make it possible to respond urgently to emergencies and prevent them even in the most remote regions.

Discussions

Manufacturers of high-tech engineering software: Dassault Systèmes, Siemens PLM Software, ANSYS, Autodesk, PTC, etc. pay considerable attention to digital twins. The interpretations of the digital twin that these companies use are often not definitions in the strict sense of the word and depend directly on the specifics of the company's activities, and sometimes on a specific project.

The dynamic increase in the frequency of use of the term “digital twin“ over the past few years has been characterized by processes that largely determine the multiple interpretations of the digital twin, resulting in the emergence of unsettled terminology.

Conclusions

The study led to the following conclusions:

– the growing interest in the topic of digital twin technology from the scientific community and the industrial sector is confirmed;

– the concept of a digital twin is considered and the aspects of its application in the sphere of industrial production are analyzed;

– the tasks of digital twins and the stages of their construction are studied;

– the advantages of using digital twins at manufacturing enterprises are revealed;

– the limitations and challenges faced by industrial enterprises in the implementation of digital twins are described;

– the examples of practical application of digital twins in the production processes of foreign enterprises and companies of Kazakhstan are considered.

Like any technology, digital twins also need to be updated to meet the latest developments in the technologies they rely on (IoT, big data, machine learning), so industries with long-term use of digital twins will need to constantly invest in this research, which can lead to additional costs.

It should be noted that, apart from domain-specific applications, most of the existing digital twin approaches are domain-neutral and therefore not limited to any particular field, which provides the complete flexibility of digital twins and the wide possibilities of their application.

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Өнеркәсіптік кәсіпорындардың сандық егіздерді пайдалану ерекшеліктері: шет мемлекеттер мен Қазақстанның тәжірибесі

Аңдатпа

Мақсаты: Өнеркәсіптік кәсіпорындардың міндеттеріне бейімделген сандық егіздерді анықтау.

Әдісі: Сандық егіздерді пайдалануды, олардың өнеркәсіптік кәсіпорындар үшін рөлі мен маңызын зерттеуге байланысты негізгі ғылыми зерттеулерді ұйымдастыру және құрылымдау мақсатында *мазмұнды талдау*; кәсіпорындардағы өндірістік процестерді цифрландырудың қазіргі жағдайын бағалауға мүмкіндік берген *талдау әдісі*; алынған нәтижелерді визуализациялауға мүмкіндік берген *графикалық интерпретация әдісі* пайдаланылды.

Қорытынды: «Сандық егіз» ұғымы қарастырылып, оны өнеркәсіптік өндіріс саласында қолдану аспектілері шетелдік компаниялар мен Қазақстанның кәсіпорындарының мысалында талданған; сандық егіздердің міндеттері және оларды өндіріске енгізудің артықшылықтары ашып көрсетілген; сандық егіздерді құру кезеңдері зерттелген.

Тұжырымдама: Зерттеу көрсеткендей, сандық егіздерді пайдалану өнеркәсіптік кәсіпорынның тиімділігі мен бәсекеге қабілеттілігін арттыру үшін жаңа мүмкіндіктер ашады. Алынған нәтижелер сандық туыстас технологияға жыл сайын өсіп келе жатқан қызығушылықты бағалауға мүмкіндік берді; талданатын дереккөздер негізінде шет мемлекеттер мен Қазақстанның өнеркәсіптік кәсіпорындарының қызметіне сандық егіздерді енгізудің табысты мысалдары қаралды.

Кілт сөздер: өндіріс процесі, сандық технологиялар, сандық егіз, виртуалды өнім, киберкеңістік, сандық егіз компоненттері.

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Особенности применения цифровых двойников промышленными предприятиями: опыт зарубежных стран и Казахстана

Аннотация

Цель: Цифровые двойники, адаптированные под задачи промышленных предприятий.

Методы: Контент-анализ с целью организации и структурирования основных научных исследований, связанных с изучением применения цифровых двойников, их роли и значения для промышленных предприятий; метод анализа, позволивший оценить текущее положение цифровизации производственных процессов на предприятиях; метод графической интерпретации, давший возможность визуализировать полученные результаты.

Результаты: Рассмотрено понятие «цифровой двойник» и проанализированы аспекты его применения в сфере промышленного производства на примере зарубежных компаний и предприятий Казахстана; выявлены задачи цифровых двойников и преимущества их внедрения на производстве; изучены этапы построения цифровых двойников.

Выводы: Исследование показало, что применение цифровых двойников открывает новые возможности повышения эффективности и конкурентоспособности промышленного предприятия. Полученные результаты позволили оценить растущий ежегодный интерес к технологии цифровых двойников; на основе проанализированных источников рассмотрены успешные примеры внедрения цифровых двойников в деятельность промышленных предприятий зарубежных стран и Казахстана.

Ключевые слова: производственный процесс, цифровые технологии, цифровой двойник, виртуальный продукт, киберпространство, компоненты цифрового двойника.