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Digital twin as a tool of the real-time enterprise management mechanism

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Purpose. This study is devoted to the actual problem of using digital doubles as a tool for an effective mechanism of real-time enterprise management in the context of modern global challenges. The paper considers the concept of a digital double of an enterprise (EDT) as a means of increasing adaptability of organizations in the context of the digital economy. **Design / Method / Approach**. The study analyzes the key factors determining the topicality of the topic, including the unprecedented level of instability of the business environment, the limitations of traditional management methods, and the potential of digital technologies to transform business processes. Special attention is paid to the ability of EDT to integrate strategic planning with operational activities. **Findings**. The paper examines the theoretical and practical aspects of the implementation of digital doubles, including their role in increasing the efficiency of resource use, risk management, and the development of new business models. **Theoretical Implications**. The value of the research lies in the development of a new concept of creating digital duplicates of enterprises based on a holistic approach based on the unification of the accounting of all enterprise assets and their presentation in the form of a multi-layered multigraph. **Practical Implications**. The practical value is expressed in the possibility of increasing the efficiency of enterprise management through the creation of digital doubles capable of autonomously performing certain tasks and interacting with each other, which optimizes the use of resources, improves decision-making processes and opens new opportunities for inter-corporate interaction. **Originality / Value**. The results of the study have both theoretical and practical significance, opening new perspectives for scientific innovation, technological progress and economic growth in the context of digital business transformation. **Research Limitations / Future Research**. An important aspect of future research is also the solution of organizational challenges associated with the implementation of such a system at enterprises. **Article type**. Case Study, Practitioner Paper.

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In today's world, business structures face an unprecedented level of dynamism and uncertainty. Globalization, technological breakthroughs, and changing consumer preferences create an environment where the ability to adapt quickly becomes a key factor for the survival and success of enterprises. This situation demands new, more flexible management approaches that allow business structures to respond promptly to changes and remain competitive. The globalization of the economy, rapid technological progress, changes in consumer preferences, and geopolitical factors create an environment where changes occur at an incredible pace. The COVID-19 pandemic has demonstrated how quickly business conditions can change and how important it is to have flexible management systems capable of adapting to new realities.

The rapid development and convergence of telecommunications, information, and computer technologies have led to the formation of a new economic landscape known as the "digital economy." This concept, introduced by Don Tapscott (1995), reflects fundamental changes in the ways value is created, exchanged, and consumed in the modern world.

Objective and tasks

The digital economy is characterized by the pervasive implementation of digital technologies in all areas of human activity, including production, trade, finance, education, public administration, and social life as a whole. A key feature of this new economic paradigm is the use of digital data as a primary resource, transforming traditional business models and creating new opportunities for innovation and growth.

Traditional enterprise management methods, which were considered effective until recently, increasingly show their inability to cope with modern challenges. Hierarchical management structures, rigid budgets, and long-term plans often become obstacles to quick adaptation to changes. Business structures that cannot respond promptly to market changes risk losing their competitive positions or even disappearing from the market.

In this context, the concept of the enterprise digital twin (EDT) offers an innovative approach to enhancing the flexibility and adaptability of enterprises. An EDT is a digital replica of an enterprise that integrates detailed models of all business processes, organizational structures, and information systems. The key feature of an enterprise digital twin is its ability to operate in real time, constantly updating according to changes in the internal environment of the enterprise and external challenges.

Using a graphical, machine-readable knowledge representation in the digital twin allows for the creation of a dynamic, easily adaptable model of the enterprise. This makes it possible to quickly analyze various development scenarios, assess the potential outcomes of management decisions, and optimize enterprise activities in real time.

A significant innovation of the enterprise digital twin is the use of contextual spaces that provide semantically structured information. This significantly increases the clarity and applicability of models, making them more accessible to a

wide range of users—from top management to line managers.

The concept of the enterprise digital twin offers a fundamentally new approach to management, creating a virtual copy of the enterprise that reflects all its processes and interconnections in real time. This allows for not only monitoring the current state of the enterprise but also modeling different development scenarios, predicting the consequences of decisions made, and optimizing enterprise activities in real time.

Materials and methods

It is important to note that the concept of the digital twin goes beyond a simple technological solution. It is a fundamentally new approach to enterprise management, based on the synthesis of the most advanced achievements in various fields of science and technology. It integrates into a single system:

1. Information technologies: the use of cloud computing, big data, and the Internet of Things (IoT) to create a comprehensive digital model of the enterprise.

2. Artificial intelligence: applying machine learning and neural networks to analyze complex interconnections, predict trends, and automate decision-making processes.

3. Data analysis: using advanced data processing and visualization methods to gain deep insights into enterprise operations.

4. Management theory: implementing modern concepts of strategic and operational management to optimize business processes.

This integration allows for the implementation of the continuous improvement principle, known as the Deming cycle (Plan-Do-Check-Act), at a qualitatively new level (Tague, 2005). Instead of periodic iterations, the digital twin ensures a continuous, ongoing optimization process:

– Planning (Plan): continuous modeling and forecasting of various development scenarios.

– Execution (Do): automated implementation of optimal solutions in real time.

– Checking (Check): continuous monitoring and analysis of results.

– Action (Act): instant strategy and tactics adjustments based on obtained data.

The digital twin allows an organization not just to react to changes but to predict them and proactively adapt, which is critically important in the highly volatile modern markets.

Moreover, the digital twin transforms the very nature of managerial activity. It shifts the decision-making process from intuitive and periodic to scientifically grounded and continuous. This allows managers to focus on strategic issues while routine operational decisions are automated.

Thus, the digital twin becomes not just a tool but a new management philosophy, enabling enterprises to achieve unprecedented levels of efficiency, flexibility, and innovation in the digital economy environment.

Additionally, the implementation of digital twins opens up new opportunities

for optimizing enterprise resource use. In the face of growing competition and resource scarcity, the ability to manage existing assets efficiently becomes a critical success factor. The digital twin allows for the identification of inefficiencies in resource use, optimization of production processes, and reduction of operational costs.

It is also worth noting the potential of digital twins in the context of developing new business models. The ability to analyze large volumes of data about enterprise operations in real time opens up new horizons for creating innovative products and services, personalizing offers for customers, and entering new markets.

In an environment where the digital economy is becoming the dominant paradigm, the ability of enterprises to effectively utilize digital technologies becomes a key factor in competitiveness. In this context, the digital twin is not just a technological solution but a strategic tool that enables enterprises to fully realize the potential of digital transformation.

Furthermore, the concept of the digital twin goes beyond the traditional understanding of the digital economy as merely transferring business processes online. It offers an innovative approach to enterprise management that combines elements of virtual reality, predictive analytics, and adaptive management.

However, the implementation of digital twins is associated with several challenges, including data security issues, the need for significant investment in technology and personnel retraining, and integration problems with existing management systems. Addressing these challenges requires deep scientific understanding and the development of new approaches to enterprise management in the digital era.

Therefore, the topic "digital twin as a tool for building an effective enterprise management mechanism in real time in the face of ongoing global challenges" demonstrates exceptional relevance and significance in the context of modern economic, technological, and management paradigms.

From a theoretical perspective, research on digital twins opens up new horizons in understanding the nature of the enterprise as a complex adaptive system operating under constant uncertainty. It promotes the development of interdisciplinary approaches, combining achievements in information technology, systems theory, cybernetics, artificial intelligence, and organizational management. This creates a foundation for forming a new management paradigm that meets the challenges of the digital era.

From a practical perspective, the concept of the digital twin offers specific tools and methods for increasing the efficiency and competitiveness of enterprises. It allows for solving such critical tasks as business process optimization, market trend forecasting, risk and resource management in real time.

In the context of digital economy development, research on digital twins opens up new opportunities for business model transformation, creation of innovative products and services, as well as for developing new forms of interaction between enterprises, consumers, and the state.

This topic also has significant potential for international cooperation and experience exchange, as the challenges of digital transformation are global and

require joint efforts from the scientific community, businesses, and state structures from different countries.

Thus, the study of digital twins as a tool for building an effective enterprise management mechanism in real time not only addresses the urgent needs of modern business but also forms the basis for developing a new management paradigm in the digital economy. It opens up broad perspectives for scientific innovation, technological progress, and economic growth, making this topic one of the most relevant and promising in modern economic science and management practice.

Results

An analysis of existing scientific contributions in this field demonstrates a wide range of approaches and applications, indicating the high potential and relevance of this technology.

Historically, the concept of the digital twin originates from Grieves' work in 2002, who proposed a three-component model that included a physical object, its virtual copy, and the connection between them for data exchange. This fundamental idea became a catalyst for further research and innovation in the field (Barricelli et al., 2019). Over time, the understanding of digital twins has significantly evolved, transforming into the concept of complex virtual constructs that not only reflect physical objects but also actively interact with the real world, processing data and influencing physical processes.

A significant contribution to the development of digital twin theory has been made by research aimed at their classification and taxonomy. A detailed taxonomy with 11 dimensions was developed, which systematized various aspects of digital twins—from data collection methods to the conceptual scope of their functionality. Based on this taxonomy, five archetypes of digital twins were identified, ranging from the simplest to the most complex implementations (Van der Valk et al., 2021). This classification not only helps to better understand the diversity of possible implementations but also lays the foundation for standardization and comparison of different approaches to creating digital twins.

A critical aspect of the research has been the clear distinction between the concept of digital twins and related concepts such as digital models or digital streams. This distinction is crucial to avoid terminological confusion and ensure accuracy in scientific discussions and practical applications (Van der Valk et al., 2021).

The practical application of digital twins covers a wide range of industries, including manufacturing, aviation, healthcare, and other sectors. Each industry has its specific requirements and implementation features, leading to the development of specialized approaches and methodologies. For example, in manufacturing, digital twins are used for optimizing production processes and predictive maintenance of equipment, in aviation—for modeling aircraft behavior and enhancing flight safety, and in healthcare—for personalized treatment and modeling physiological processes (Qi & Tao, 2018)

The technological aspects of creating digital twins are also the subject of active research. Particular attention is paid to integrating such technologies as the

Internet of Things (IoT), cloud computing, big data, and artificial intelligence. IoT provides real-time data collection from physical objects, cloud computing offers the necessary computational power for processing this data, while big data technologies and artificial intelligence enable the analysis of vast amounts of information and the identification of hidden patterns. The symbiosis of these technologies creates a powerful platform for implementing complex digital twins with a high degree of autonomy and adaptability (Lee et al., 2024)

At the same time, the implementation of digital twins faces several challenges that are also the subject of scientific research. Among the key problems are ensuring data security, high development and implementation costs, and regulatory aspects. Data security is especially critical, as digital twins operate with large volumes of sensitive information that can become a target for cybercriminals. High implementation costs remain a significant barrier for many businesses, especially small and medium-sized enterprises (Van der Valk et al., 2021).

In the context of these studies and challenges, my work proposes an innovative approach to creating enterprise digital twins, distinguished by its holistic nature. Unlike most existing research, which focuses on creating digital twins of individual objects or business processes, the proposed concept views the enterprise as a single organism, all components of which are interconnected and interact with each other.

The key innovation of the proposed approach is the unification of accounting for all existing enterprise assets and the integration of these objects and subjects into a single graph structure, namely a multigraph. This structure not only reflects the connections between different elements of the enterprise but also explains the essence of their interactions. The multilayer architecture of the multigraph allows for describing various aspects of interactions between enterprise objects, including the intensity and frequency of communications.

An important feature of the proposed model is the ability of each digital twin of a specific object to initiate the launch of a business process. This creates a dynamic system where digital twins not only passively reflect the state of physical objects but also actively influence business processes. This approach ensures feedback, which is recorded in the accounting system, allowing the digital copy to perform certain tasks autonomously, without direct participation of the physical object.

Furthermore, the proposed concept opens up new possibilities for autonomous communication between enterprises. This could lead to revolutionary changes in the nature of intercorporate interaction and cooperation, allowing enterprises to collaborate more effectively to solve common tasks and optimize supply chains.

The potential of the proposed model to enhance enterprise management efficiency is significant. It can contribute to resource optimization, improve decision-making processes, and increase overall business operation efficiency. Moreover, this model opens up new avenues for research in the field of digital twins, artificial intelligence, and graph theory in the context of enterprise management.

Further research within this concept will focus on developing specific methodologies for its implementation. This includes addressing challenges related to

the creation and maintenance of complex multigraph structures.

An important aspect of future research is also addressing organizational challenges associated with implementing such a system in enterprises. This includes developing change management strategies, training personnel to work with the new system, as well as integrating digital twins into existing business processes and information systems of enterprises.

Particular attention should be paid to studying potential ethical aspects associated with the autonomy of enterprise digital twins. This includes questions of responsibility for decisions made by autonomous systems, ensuring transparency of decision-making algorithms, and protecting privacy and personal data in the context of deep digitalization of business processes.

If at first digital doubles were considered mainly as a tool for automation and increasing the efficiency of processes, with the development of the Industry 5.0 concept, the focus shifted to a human-centered approach (Wang et al., 2023).

A significant contribution to the development of the theory was made by research on human digital doubles (HDT), which are considered as a key method of implementing human-centricity in intelligent production systems. HDTs are a digital representation of people aimed at enhancing human capabilities, unlocking potential, and prioritizing physical and mental well-being in smart manufacturing systems.

This context emphasizes the need to develop new management models of business structures that take into account not only technical aspects, but also the human factor. It becomes important to create such management systems that would allow to harmoniously combine human abilities (creativity, flexibility of thinking, the ability to make decisions in conditions of uncertainty) with the capabilities of automated systems.

In this context, a holistic approach to the creation of digital doubles of the enterprise, which would take into account both technological aspects and people-centered principles of Industry 5.0, becomes particularly relevant. This approach has the potential to create more efficient and adaptive management systems that meet the modern challenges of the business environment.

Conclusions

Thus, the proposed concept of a holistic approach to creating enterprise digital twins not only advances existing scientific developments in this field but also opens new perspectives for research and practical application of digital technologies in enterprise management. It has the potential to significantly impact business operation efficiency, intercorporate interaction, and the overall management paradigm in the era of digital transformation.

The use of multigraph structures to model relationships between various elements of the enterprise, including human capital, allows taking into account not only the technical aspects of the enterprise's functioning, but also social interactions, employee competencies and their development potential. This creates prerequisites for a deeper understanding of the processes taking place in the organization and making more informed management decisions.

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