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Enterprise performance management based on digital twin technology in the fifth-generation industry

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Abstract

In the context of the increasing need to improve the management efficiency of enterprises that support the implementation of the principles of digital transformation based on the concept of the fifth-generation industry, the relevance of research on the development of appropriate systems in terms of ensuring continuous targeted and sustainable development, customer-centricity and social orientation of production is increasing. Digital twin technology and its multi-agent implementation act as effective

means of building enterprise performance management systems. At the same time, the lack of scientific research in this area determines the purpose of the article, which is to develop a product-resource approach to enterprise performance management based on digital twins in the fifth-generation industry. A distinctive feature of the proposed approach developed by the authors is the use of dynamic enterprise performance management technology based on digital twins, which ensures the integration of business processes and resources used at the level of not only one enterprise, but also at the level of network value chains based on a common digital platform of the business ecosystem. The paper analyzes approaches to the intellectualization of enterprise management, on the basis of which the requirements for an enterprise performance management system are formulated, ensuring the solution of interrelated tasks of targeted enterprise development, the formation of flexible value chains, and the rational and sustainable use of enterprise resources. The possibilities and disadvantages of the efficiency management process in EPC class systems are analyzed. The paper substantiates the use of digital twin technology and its multi-agent implementation to build an enterprise performance management system in the context of mass customization and the network nature of value chains in the fifth-generation industry. A process for managing the efficiency of enterprises at all stages of the life cycle based on the technology of digital twins of products and resources has been developed, dynamically ensuring the targeting, adaptability and sustainability of the functioning and development of the enterprise.

Keywords: fifth-generation industry, targeting, adaptability, sustainability, enterprise performance management, product digital twin, resource digital twin

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Introduction

The main goals of the digital transformation of enterprises include increasing labor productivity, improving the quality of products and services provided, mass customization of production, flexibility and adaptability of production and business processes due to the widespread use of technologies using digital platforms and digital twins [1–3]. Full automation of production very often leads to negative social consequences: an increase in unemployment, a decrease in creativity in work, violations of the protection of production systems from unintended and malicious actions, overproduction of products with environmental violations, excessive consumption of expensive resources: material, energy, financial, which generally leads to unstable economic development.

In the process of digital transformation, based on the principles of the 4th generation industry, new forms of organizing corporate relations of enterprises are being developed within the framework of creating business ecosystems, forming digital and network enterprises based on integrated software and hardware platforms

[4–6]. The basis for the creation of such enterprises are new digital technologies such as Industrial Internet, cloud technologies, processing of big data, machine learning, multi-agent systems, generative artificial intelligence, etc. The fourth-generation industry concept allows for flexible digital and networked enterprises that dynamically learn how to build value chains based on big data to meet specific consumer needs.

In terms of works reflecting the possibilities of building multi-agent systems that optimize the use of resources in dynamic business processes based on simulation, one should note [7–9], which presents effective methods of dynamic support for operational management decision-making. In [10], an approach is proposed to form various scenarios for the strategic development of socio-economic systems using an evolutionary optimization algorithm based on simulation modeling. At the same time, the operational and strategic management contours are considered separately in these works.

In modern conditions of digital enterprise development, a more rapid strategy update is required based on the need for continuous business process changes and the reverse dynamic effect of strategy changes on operational business processes. At the same time, the main focus in such production systems is on the operational management horizon, and issues of strategic planning for sustainable development on a long-term time scale are practically not considered. In addition, the requirements of mass customization, when the consumer interactively participates in the development and customization of products for their own needs [11], complicate the solution of the tasks of coordinating goals between participants in joint economic activities. The emerging problems of digital transformation of enterprises based on the principles of the 4th generation industry necessitate further intellectualization of enterprise management processes, ensuring their targeted, adaptive and sustainable development.

The above-mentioned principles of enterprise development in recent years are reflected in the concept of the 5th generation industry [12, 13], in which production becomes human-centered not only from the point of view of consumers of products and services, but also from the point of view of manufacturers themselves, that is, employees of enterprises, for whom their role in decision-making increases, with different levels of control, even in robotic production. At the same time, production requires greater safety and sustainability in terms of the consumption of necessary resources. Enterprises of the 5th generation industry acquire a self-organizing form of functioning in accordance with dynamically updated goals, which are determined not only by the needs of changes in the market situation, but also are set taking into account the social needs of society in the broadest context.

In parallel with the concept of the fourth and fifth generation industry, the concept of creating smart enterprises (intelligent enterprises) is developing in the world [14–16]. In the concept of smart enterprises, the main principles are to achieve sustainable development, increasing trust between enterprise participants, conducting investment research by modeling market behavior, rethinking strategy and business models, flexible budget planning, continuous monitoring of business processes, receiving feedback at all levels of management by measuring business results, in-depth understanding of processes and interdependence. between them. This concept fully implements the approach to creating self-learning intelligent enterprises on a new technological basis.

In [17], the principles of intelligent, self-configurable production are developed, which reflect the idea of a continuous cycle of goal setting, configuration and reconfiguration of value chains, monitoring and controlling the execution of business processes in order to ensure sustainable development based on the use of neural network modeling technologies, processing big data, and multi-agent systems. This formulation of the problem is very close to the established approach to continuous engineering and digital transformation of enterprises, outlined in [18]. At the same time,

the sustainability of an enterprise will be understood as an enterprise capable of "... finding the optimal ratio between all its elements, establishing connections between them that make it possible to maintain vital parameters at a given level for as long as possible, effectively countering the disturbing effects of the external environment" [19]. From the point of view of sustainability, it is important to ensure that all resources are balanced in order to achieve the targets of efficiency and effectiveness, as well as their compliance with the necessary standards of use in terms of meeting the needs of the external environment.

To implement the principles of intellectualization of production and business processes in the fifth-generation industry, the article proposes the construction of an enterprise performance management system that would ensure the solution of the following interrelated tasks:

- Targeted development of enterprises aimed at flexible and dynamic formation of goals and plans in accordance with the rapidly changing environment and social needs.
- The formation of flexible value chains that ensure the dynamic realization of market needs in accordance with the strategic and operational objectives of the enterprise.
- Sustainable and balanced use of enterprise resources in production and business processes, aimed at safe, environmentally friendly and socially justified use.

The article proposes to build such an enterprise performance management system based on the development of a product-resource approach to the organization of digital twins using multi-agent technology that allows dynamic monitoring of strategic goals by measuring process efficiency indicators, accumulating big data and timely updating of the strategy. The implementation of the proposed approach will require the creation of a new generation of digital platforms based on the principles of the 5th generation industry.

1. Analysis of the traditional approach to enterprise performance management in an EPM system

In modern conditions, the main goals of enterprise development are continuous innovation, ensuring sustainable development, environmentally friendly production, flexibility, cost-effectiveness, quality improvement, speed and adaptability of production and business processes, which determine the vector of development of targeted companies. At the same time, the companies' focus is realized at the strategic and operational levels.

- At the strategic level, business objectives are considered in all areas of activity and promising, possibly new types of activities are highlighted, taking into account the ongoing changes in the external environment and the current state of the company's competencies and potential.
- At the operational (product) level for certain types of activities which determines the possibilities of organizing production and business processes, taking into account the interests of all stakeholders: consumers, investors, management, staff, external organizations.

At the strategic level, business goals are usually organized in the form of various types of balanced scorecard (BSC) or strategic maps [20]. Classically, the goals of the main activities are reflected at the third level (the level of internal business processes). Types of activities in modern conditions of client-centricity and dynamic implementation are interpreted as organizational services provided to various categories of consumers [21]. On the other hand, the declaration of the possibilities of implementing services is reflected in the concepts of competencies and abilities of organizations [22].

A set of key performance indicators (KPIs) is used to measure the achievability of goals. Libraries (repositories) containing descriptions and templates for calculating indicators are usually used to select a set of goals and KPIs in accordance with the chosen strategy [23]. Subsequently, these indicators are reflected in specialized information and analytical systems equipped with tools for analyzing the effec-

tiveness of business processes (Enterprise Performance Management, EPM) [24–26] and extracting knowledge from the collected data in process monitoring (Process Mining) [27].

For the targeting development of enterprises, it is very important to ensure the interaction of the organization's goals at the strategic level and key performance indicators at the operational level. The process of correlating goals with operations that ensure their fulfillment is called goal operationalization [21]. To move from strategic goals to operational goals, goal environment diagrams are usually used [28]. Such interaction is carried out as a result of consistent detailing of strategic goals in the form of sets of measures to achieve them. For events, in turn, the business processes that execute them and key performance indicators that measure the results of the processes are determined. An example of a diagram of the goal's environment is shown in *Fig. 1*. In enterprise performance management systems [25], key performance indicators are monitored; they are used to analyze the achievement of goals and possible subsequent changes in both the regulatory KPIs and the goals themselves at the BSC level.

The business performance management process in the EPM system is shown in *Fig. 2*.

Let's look at the business performance management process in the EPM system in more detail. Based on the company's strategy and external sources of information about the competitive environment, a balanced scorecard and goal environment diagrams are built.

The development of business processes based on BSC and goal environment diagrams is usually carried out in BPMN notation and implemented using Low-Code tools. The EPM system binds software modules that collect data on the performance of key performance indicators to software components that implement business process operations, and sets planned process performance indicators (KPIs).

As a result of the information collection, a special EPM module that implements methods for extracting knowledge from processes (Process Mining) is quickly

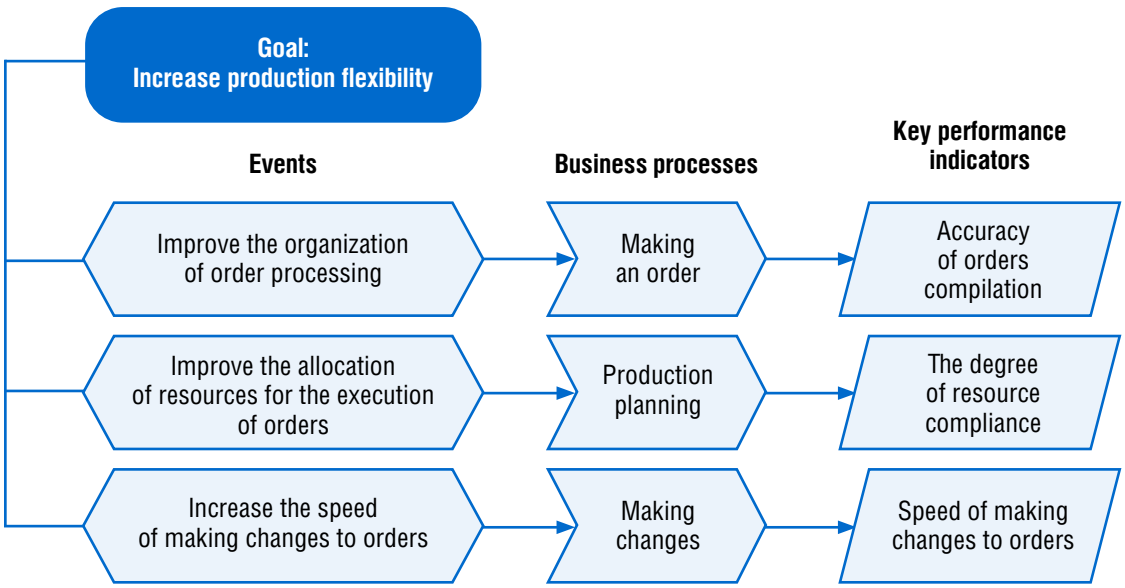

Fig. 1. Diagram of the goal's environment.

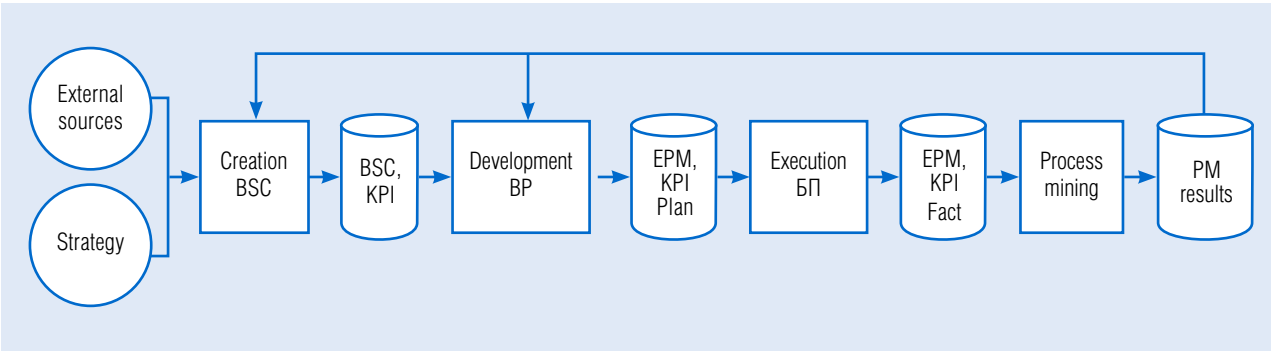

Fig. 2. The process of enterprise performance management in the EPM system.

analyzed for the performance of operations. At the same time, the analysis of both individual indicators and their integration by convolution and subsequent evaluation is carried out.

Based on the data obtained, both the current situation is analyzed and a forecast is made using machine learning methods for necessary changes in tactical goals at the business process level and strategic goals at the enterprise level.

The described process of enterprise performance management in the EPM system is successfully applied in traditional business, which are characterized by a relative regularity of operational processes, and the main thing is to monitor key performance indicators that regulate the achievement of goals, and strategic goals are formed rather for new business processes that are subsequently implemented on a regular basis. The structure of the business processes themselves and their participants is relatively stable.

The fourth-generation industry and its development in the fifth generation are characterized by the high variability of business and production processes within the framework of mass customization of products and services provided, which are carried out in business ecosystems based on digital platforms. In [18, 32], principles and models for creating network enterprises for changeable business goals were developed, providing a dynamic configuration of business and production processes based on digital twin technology and asset administrative shells implementing them. For such enterprises, it is necessary to improve the methods of managing the effectiveness of enterprises, taking into account the implementation of the requirements for dynamically ensuring the targeting, adaptability and sustainability of the enterprise.

2. Enterprise performance management based on digital twin technology

In the modern mass-customized production, an original process configuration can be built for each product or product-related project, in which different performers are involved at each moment, selected on a digital platform. Making decisions about the development of product lines, the transition to the production of new products and the modernization of existing ones, and the customization of products to meet the needs of specific customers necessitate the management of not only processes but also products at the operational level. Dynamic product management also involves the dynamic configuration of business processes for changing business goals, requiring the selection of the best resources under certain constraints on their use and compliance with sustainability require-

ments, and in a network environment on a single digital platform of the business ecosystem.

The specifics of the fifth-generation industry make it necessary to accelerate product innovations (updating of nomenclature, technologies, mass customization), on the one hand, and ensuring the sustainability of the use of all resources in processes, on the other hand. From this point of view, the goals of the process level should reflect the goals of customer orientation, flexibility and adaptability of business and production processes, and the last level of the strategic map related to the use of resources and technologies should reflect the goals of sustainability. In this regard, the importance of developing a product-resource approach to improving the efficiency of enterprise management in the digital economy is increasing.

In the product resource approach, the innovative stage of product quality development is very important, where a set of functional and non-functional product requirements is formed, which is the basis for product and service design and specification of subsequent SLA – Service Level Agreements with future business partners. These requirements specify the key indicators of process efficiency in relation to the specific parameters of the products produced and the resources used. The formation of requirements is based on the analysis of the external market of products and technologies and is implemented using the QFD quality deployment method and the FMEA method of analyzing the types, consequences and causes of potential nonconformities [29–31].

The analysis of the implementation of requirements for the production of products and the use of resources from the perspective of achieving operational goals in the industry of the fourth and fifth generations directly in the traditional EPM class system is almost impossible to implement due to the large number of qualitative and quantitative characteristics and their dynamic changes from one type of product to another. In this regard, it is advisable to develop a dynamic technology for enterprise performance management based on digital twins.

Digital twins, in accordance with the RAMI architectural framework [2], are information models that reflect at each moment the state of both manufactured products and used resources (equipment, production lines, entire enterprises). Moreover, the formation and use of product information by stages of its life cycle is carried out in the process of interaction of the digital twin of the product with the digital twin of resources

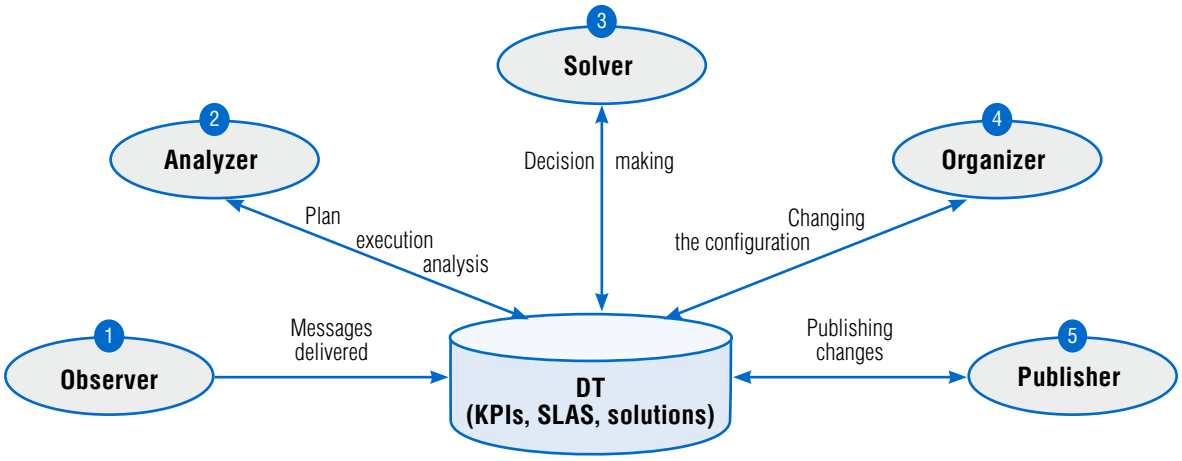

Fig. 3. Architecture of the intelligent agent (built on the basis of [17]).

based on multi-agent technology [14]. For a digital twin in the form of an intelligent agent, a typical set of components is proposed that allows automating the processing of various situations in the decision-making process about responding to events both in the outside world and when coordinating interaction with other agents (*Fig. 3*).

Consider the main components of an intelligent agent that implement the functions of situation processing:

- Observer collects data on the behavior of real objects displayed in the digital twin, interprets the received data and enters it into various submodels of the digital twin.
- The analyzer identifies possible deviations from the regulatory values of key KPIs and Service Level Agreements (SLAs).
- The solver makes decisions about the need to change the states of real objects and initiates interaction (negotiations) with other intelligent agents, makes decisions based on the results of negotiations.
- The organizer carries out information exchange with other intelligent agents by sending requests and receiving responses.
- The publisher records the decisions made and updates key performance indicators and SLA indicators.

In accordance with the presented architecture of an intelligent agent implementing the functions of a digital twin, the schematic diagram of the enterprise performance management process (product manufacturing) is implemented in the form of a technological scheme shown in *Fig. 4*.

Let's consider this scheme in more detail. The process of developing a new product concept should correspond to the goals that are laid down in the company's strategy in the form of a set of requirements, reflected in a balanced scorecard. At the same time, a product digital twin (PDT) is created, into which key performance indicators are transferred from the diagrams of the environment of the BSC goals, for example, the accuracy of the order's compliance with the originally formulated requirements, the degree of compliance of resources with the order, the speed of order execution, etc. Using the domain ontology, services for analyzing

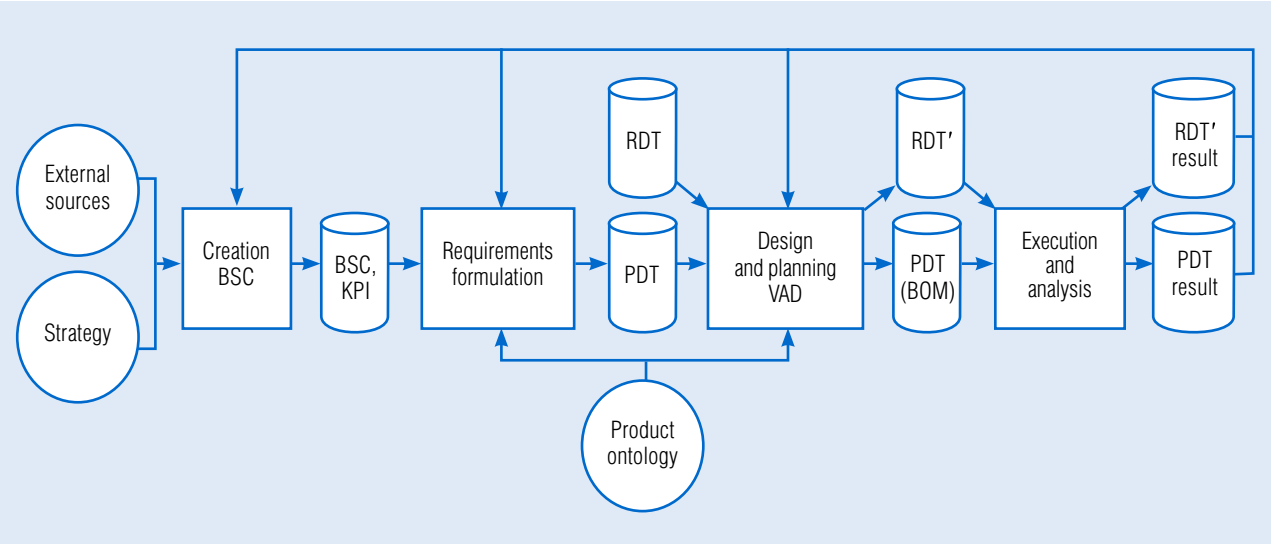

Fig. 4. The process of managing the performance of product manufacturing based on digital twin technology.

the market of similar products, materials, technologies, competitors and suppliers and selecting promising consumer characteristics of a future product are launched from the digital twin. As a result, functional and non-functional requirements are formed, which are entered into the corresponding submodel of the PDT.

In the process of designing a product from the digital twin of the product, a service is launched to form the design of the product and the value-added chain (VAD) with the selection of specific business partners for its implementation. As a result of the design in the digital twin of the product, a description of its structure (Bill of Materials, BOM) and the structure of the technological process are displayed in the subsystem of the product design.

Resource digital tweens (RDT) are involved in the design process, which reflect the profiles of the ability to perform various operations. Resource digital tweens are created both at the level of enterprises that are part of a common business ecosystem on a single digital platform, and at the level of specific equipment that implements operations. As a result of the selection and coordination of resources during the design process, RDTs capture participation in a specific value chain for the subsequent implementation of an innovative project. Then at the planning stage, quantitative and qualitative characteristics of the product production plan are formed, which is specified in the form of service level agreements with subcontractors and recorded in both the digital twin of the product and the digital twin of resources.

The production process starts from the product digital twin according to the plan contained in this twin, and unfolds according to the designed value chain in a sequence of operations. In the process of production (execution of value chains), statistics are accumulated in digital counterparts of products and resources on the progress of work, which, as noted in the previous section, is used both to quickly respond to changes and to analyze goals in the short and long term.

Thus, the analysis of the efficiency of the use of individual resources is carried out by launching analytical and predictive services in the digital counterparts of resources, and analyzing the effectiveness of end-to-end processes by launching the corresponding services from the digital counterparts of products. As a result of the analysis, there may be a revision of the parameters of requirements and key performance indicators related to the production and provision of services, as well as a possible change in the strategic goals of the enterprise.

During the execution of the main processes, monitoring operations can be launched to analyze not only their operational efficiency, but also the analysis of related supporting processes: electricity consumption, materials, environmental protection measures, information protection, etc. For this, a sub-model of regulatory attributes for resource use in terms of compliance with the conditions of sustainable operation must be set in the resource digital tweens. The analysis of the operational efficiency of resource use provides a basis for forecasting the sustainability of both the main and supporting business and production processes.

Compared to the approach to managing the efficiency of business processes in the EPM system, this approach based on digital twins has a number of advantages.:

1. Providing enterprise performance analysis using digital counterparts for both the system as a whole and for individual products and resources.
2. Increasing the efficiency and adaptability of value chains to meet changing market goals.
3. Ensuring the integration of business processes and resources used at the level of not only one enterprise, but also at the level of network value chains formed on the basis of a common digital platform of the business ecosystem.
4. Providing analysis and management of the sustainability of resource use in various production and business processes.

Conclusion

The digital transformation of enterprises based on the concept of the fifth-generation industry involves massive customization of production, increasing the creative role of employees, the social orientation of economic activity of enterprises and necessitates the use of artificial intelligence technologies in optimizing business processes and the use of resources in them. As a result of the research we conducted, it can be concluded that in order to solve the problem of increasing the performance of enterprise management, it is necessary to create a system based on digital twin technology, which should ensure continuous targeting and sustainable development, customer-centricity and social orientation of production.

The analysis of traditional enterprise performance management systems has shown the limitations of their application for the dynamic operating conditions of enterprises, which necessitate timely changes in the strategic and operational goals of enterprises in accordance with changing product needs, taking into account the requirements of sustainable resource use.

The enterprise performance management process developed in the work based on the use of digital twin technology for products and resources at all stages of the life cycle allows you to quickly reflect the state of all related processes, monitor compliance with requirements and key performance indicators, predict the development of situations using machine learning methods and tools, and formulate proposals for correcting goals at the operational and strategic levels.

The application of the dynamic technology we developed for enterprise performance management will make it possible to fully implement the principles of the fifth-generation industry in the digital transformation of enterprises and increase the efficiency of enterprise management at all stages of the life cycle. ■

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