Digital transformation model based on the digital twin concept for intensive aquaculture production using closed water circulation technology

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Abstract. The article discusses the complex digital transformation problem for the functioning aqua-biotechnological industrial company. The structure of the information model and digital twin for such objects is identified and described. The results of a comprehensive engineering and economic inspection of the state of the biotechnological, engineering, and economic system from the point of view of digital transformation are described. A conceptual scheme of the enterprise functioning based on the results of digital transformation is presented. The target effects of modernization and reconstruction of the existing biotechnological enterprise based on the end-to-end digital technologies of the fourth industrial revolution are formulated.

1. Introduction
Currently, such areas of research and development as effective biotechnologies [1-3] and digital transformation of industry [4-6] are of high relevance. The combination of these approaches in one production should provide a synergistic increase in efficiency across a wide range of criteria. Within the framework of this work, we will describe approaches to building a digital twin of an industrial enterprise in the field of high-intensity aquaculture production, the structure of such a twin, and the target effects of its implementation for the real production complex.

The research base and testing ground for the implementation of this work is the real industrial aquaculture plant using closed water circulation technology in the Kursk region (http://karmut.ru/). The plant was put into operation in 2009. At the enterprise with the author's participation, a full-scale technology was implemented for the significant volumes of sharptooth catfish production. A complete closed production cycle has been realized. It includes fry breeding and rearing, commodity fish rearing to marketable conditions, fish processing. High-protein aquaculture feed innovative production has also been created. This technology uses fish processing waste. The closed waste-free protein cycle has been implemented. The innovative industrial trout cultivation technology by closed water circulation systems for the Central Russia climate zone was developed and tested in 2018-2020. The first commercial batch of trout was received in 2020.

This research includes several stages. First, an inspection of the real aquaculture industrial enterprise based on closed water circulation technology was conducted. Secondly, digital models and twins for the biotechnological plant were developed. Furthermore, digital models and counterparts of
biotechnological production were created. Finally, the digital transformation concept for various aspects of the functioning of a high-tech enterprise in the field of aquaculture cultivation has been developed.

2. Materials and methods
The main task of this work is to develop the real enterprise information model and a digital twin concept and build their prototypes then. A comprehensive survey of the object was carried out initially. Three major subsystems were identified as the first approximation. First of all, it is the biological component of the target system. Second, it is the engineering equipment and engineering processes. They support the existence and growth of the biological component. They include engineering-technical activities of the personnel and engineering outsourcing. Moreover, business processes become a subject of information modeling. They include management, marketing and promotion, customer service, logistics, accounting, HR management, and some others. All these objects, processes, and aspects in digital transformation generate data flows. The data totality forms digital models and twins.

The survey information bases for each subsystem are different. We used available data sources in our work. This is the archive documentation formed during the enterprise operation time (since 2009), and it includes original design documents and design data about the structure, equipment, and communications modernizations. We used the equipment operating data. This was received from operational logs, monitoring files, and the incidents investigation documents. As a result of the inventory, discrepancies between the design documentation and the actual composition and architecture of the production complex were revealed. An updated engineering BIM model of the production complex was created to keep the data up-to-date. For the technological processes efficiency, it is desirable to regularly take into account many parameters. This is essential in order to maintain the optimal parameters of the aquatic habitat of aquaculture, feeding regime, control of fish growth, and others. Currently, this is often done by maintaining paper journals and electronic databases. Increasing the functionality and reliability of sensors, data transmission media and remotely controlled actuators in recent years has provided an alternative solution to the problem. These new technical capabilities were accompanied by a significant reduction in the hardware and software costs [7]. It is possible to make human-independent data flows and control algorithms in the communication environment of "smart things". Based on this approach, a concept of a smart digital biotechnological production based on the Industrial Internet of Things (IIoT) technology was developed and the prototype was built.

A separate task is to build a monitoring and predictive modeling system for the parameters of cultivated aquaculture. To do this we need a system for monitoring the number of fish in cages, their condition, and characteristics according to physical sensors. The analysis of video images and the ultrasonic location of containers is promising. Artificial intelligence and machine learning technologies based on instrument data can be used to interpret the data. The method of mathematical modeling based on the system of ordinary differential equations is used for predictive modeling of the aquaculture population. They relate the aquaculture growth rate to the parameters of the aquatic environment (temperature, oxygen saturation, and pollution concentration) and feeding regimes. The prospective goal of the work is to create an adequate mathematical model. The quality criterion is the coincidence of the operational monitoring data of the biological system with its calculated parameters throughout the entire growing period.

The third component of the enterprise's digital twin is business process data. These include management and tax accounting, marketing, customer relations, logistics, and others. The majority of this data is available in the ERP system [8]. The reference company has resources for the ERP system development. The main idea is the human-independent business processes data online formation, just as data arise. This applies to accounting in logistics and warehouse accounting based on material flows end-to-end monitoring by using machine-readable barcoding and/or RFID technologies. Also, converting a document flow into a machine-readable form based on QR codes has been developed. The
most important is to combine all sets of management and business data into a single database. Database access is required for all employees within their permission.

A complete enterprise digital twin arises when these data streams are synchronized and analyzed comprehensively [9-10]. Such a multi-factor digital twin is an innovative tool for biotechnological production functioning analyzing and optimizing. The approach based on digital twin technologies, the Internet of Things, data analysis, artificial intelligence, and machine learning in the Russian intensive high-tech industrial aquaculture production is used for the first time under our information.

3. Results
A starting version of the information model was built during this project. It is based on the results of studying the documentation, engineering, and business surveys of production, which consists of several components.

The aqua-biotechnological model is described by a system of equations. They are linking the aquaculture grown changes in fish tanks with the parameters of the aquatic habitat and feeding regimes. The essential parameters are temperature, the content of dissolved oxygen in the water, and pollution of the aquatic environment by aquaculture vital products. The water contaminant, fish tanks' lighting modes, and bacteriological pollution of the habitat were also taken into account. When feeding regime modeling, we must know the main feed nutrients (protein, fats, and carbohydrates), the size of feed pellets, the frequency of feeding, and the pellet's destruction in the aquatic environment, and some others. In the future, detailed characteristics of feed mixtures will be taken into account, including the content of vitamins, trace elements, and amino acid composition. The system of equations includes differential equations describing the dynamics of the mass of aquaculture and environmental parameters, as well as algebraic equations describing the conservation of energy and mass of various components of biotechnological production. The equation coefficients describe the relationship between the engineering systems control effects of, habitat and feeding parameters and the weight gain of aquaculture. These coefficients in the zero approximation correspond to the dependences given in the literature. They were adjusted based on the operating experience of the reference biotechnological production. The coefficients change significantly at increasing production intensity. At extreme loads, the fish-water ratio in the fish tank can be 1:1 for sharptooth catfish aquaculture or 1: 3 for trout. A mathematical feature of the system of equations is the presence of several times scales. Thus, the dynamics of dissolved oxygen and nitrogen-containing aquaculture secretions are determined at times in tens of minutes. Cycles of feeding and assimilation of nutrients by fish have a duration of several hours. The daily cycle exists too. The biotechnological cycle duration is from 6 to 24 months. Thus, we have a rigid system of differential equations with a characteristic time difference of up to five orders of magnitude. This must be taken into account when numerical algorithms choosing. As part of the reference production, we worked with two aquacultures. They are the sharptooth catfish and trout. For the mathematical model, the difference between aquacultures is equivalent to the equation coefficients difference. At this stage, the biotechnological subsystem modeling accuracy is insufficient. It will be refined based on experimental data. The engineering systems information model includes a BIM model of aquacultures growing closed water circulation technology industrial plant. The model architecture plans describe the spatial structure only. Engineering systems are worked out in detail, with the construction and connections of all elements, eliminating inconsistencies and collisions. A full-fledged digital project of the current state of industrial equipment was created. Also, the industrial installations modernization project has been developed using digital BIM technology. This includes designing a sensor system for all equipment components and engineering communications. Controlled parameters are selected according to two different types of requirements. First, the parameters essential for the biotechnological system are recorded. Secondly, parameters related to the operability and operating modes of engineering equipment are monitored. The attribute parameters of the information model include links to technical documentation, equipment passports, operating conditions, and maintenance regulations regiments.
During data structure designing for each system (biological or engineering), a list of essential parameters, the frequency of their fixation, as well as a register of measurement methods and data transmission are compiled. There are several methods and points to measure most of the parameters. In the simplest case, the data is captured by the staff and recorded in logs. A high level of automation corresponds to the data stream generation by "smart things". This is achieved by integrating sensors and data transmission systems built into a single data transmission system inside and outside the facility. In our case, only about half of the essential engineering and biotechnological parameters are currently controlled. A significant part of decisions is made competently. It is based on the "inner impressions" of the staff. Productivity in this case is provided only by the high experience and qualification of key employees. This approach is not optimal at this stage of technological development. During this work, the process of transition to end-to-end digitalization of the biotechnological process was designed. This implies the installation of built-in and stand-alone sensors at all key points of the system. All sensors are integrated into a single data transmission system. Previously installed sensors are partially wired. At the same time, they use different interfaces. Planned for installation a new array of sensors is initially designed to be continuously included in a wi-fi data transmission field. Existing sensors will be integrated into the information space by new integrating controllers connected to wireless networks. A single data transmission environment is formed within the enterprise. Data storages allow using of full data sets for the entire time of the system. The information system core provides management of engineering equipment, emergency diagnostics, and information support for personnel decision-making. The enterprise's digital twin system and management (decision-support) system interact with both engineering components and personnel. The core of the system generates data, signals, and commands for the actuators and the personnel. The data flow for the staff is delivered in an individualized and targeted manner to personal devices, both connected to a local wi-fi data transmission system and remote mobile devices on the global Internet. This takes into account the regulated rights of access to data and job responsibilities. Notification of collisions, conflicts, and special situations, as well as an escalation of the decision-making level, is performed according to the algorithms laid down at the development and configuration of the system core software. Reducing the number of employees even at the first stage of digitalization of production is not less than 50%. Most of the engineering operations (diagnostic and operating mode settings) are performed by sensors and actuators integrated into a single digital environment. The concept is constructed and the project of complex digitalization of production and automation of engineering and operational activities on the "Industrial Internet of Things" technology in combination with the production facility digital twin is developed.

At this stage, the digital twin of economic and management activity is quite well developed. Its core is an ERP system. It is based on 1C software. Business processes digitalization is ahead of engineering activities digitalization now. This project objective was to use management accounting data to reduce costs and develop criteria for selecting optimal technological and engineering solutions. Economic activity digital twin improvement will be carried out at the following work stages.

The result of the work is the digital transformation concept for the existing high-tech enterprise in the field of intensive aqua-biotechnologies. The implementation and implementation of the concept gradually create a commercially valuable intellectual product in the future. Specific schemes, algorithms, design solutions, the composition of the software used, equipment models, and other intellectual property objects are protected by the enterprise in the "know-how" mode.

The general conceptual scheme of a deep digital transformation of a biotechnological high-intensity enterprise is presented in Figure 1. This concept is currently being implemented in the course of design work on the modernization and reconstruction of the existing products in the Kursk region.

For the digital transformation of biotechnological production, a range of innovative end-to-end technologies is used to achieve targeted effects. Among them, there are the technology of BIM-design; the creation of digital counterparts of complex engineering objects, and many others (Industrial Internet of Things, Artificial Intelligence, Computer vision, Big Data, Machine & Deep Learning, Data Mining).
4. Discussion
In the course of the work, the target effects for digital technology large-scale introduction for the transformation of intensive aquaculture production using closed water circulation technology are considered. We expect a significant increase in the manageability, reliability, and efficiency of the enterprise. According to preliminary calculations, a twofold reduction in the number of personnel, a reduction in operating costs by 15-20%, and an increase in feeding efficiency of up to 10% can be achieved. The target effects will be the possibility of calculating the engineering decisions consequences, changes in biotechnological regulations, modeling the management decisions consequences, and reducing commercial risks. Based on engineering and biotechnological subsystems' big data array, it is possible to perform predictive analysis for various scenarios of aquaculture cultivation, as well as a medium-term development strategy. The use of artificial intelligence and deep machine learning methods will optimize current production processes and identify patterns in the applied biology of growing valuable aquaculture.

5. Conclusion
In the described project, the Higher Engineering School of MEPhI experts together with the specialists of the industrial enterprise developed the concept of a deep digital transformation of the existing high-intensity aquaculture company using closed water circulation technology. The design project of reconstruction and modernization of the enterprise based on end-to-end digital technologies of the Fourth Industrial Revolution is been developed. The implementation will result in reducing production costs, improving quality, improving staff skills, and creating high-performance employments.
The problem of the deep digital transformation of the existing industrial aqua biotechnological enterprise is considered. The structure of the information model and digital double for such objects is identified and described. The results of a comprehensive engineering and economic survey of the state of the biotechnological, engineering, and economic system from the point of view of digital transformation are described. A conceptual scheme of the enterprise functioning based on the results of digital transformation is presented. The target effects of modernization and reconstruction of the existing biotechnological enterprise based on end-to-end digital technologies of the Fourth Industrial Revolution are formulated.

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