Formation and selection methodology of digital transformations programs for an industrial enterprise using machine learning algorithms

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Abstract. The article developed a Methodology for the formation and selection of digital transformation programs of an industrial enterprise using machine learning algorithms. The method allows creating a set of valid alternative options for digital transformation programs for the production activity of an industrial enterprise by a set of workarounds for a multilayer graph model. The choice of the optimal program is carried out by assessing the weights of the workarounds of the graph by a set of Key Performance Indicators (KPIs). The method is based on the presentation of the structure of an industrial enterprise by weighted oriented graphs which determine the structure of a neural network, and its subsequent training on arrays of source information. Each hidden layer of the graph model determines any component of the production structure of the enterprise, and the neurons in them are the components of this structure. As a basic part of the digital transformation is determined a automated workstation and a cyber-physical system. The PyTorch library for the Python 3.8 programming language is used as the main tool for implementing the method.

1. Introduction
The current state and prospects for the development of industrial production are characterized by increased requirements for the organization of production processes, labor productivity, and the quality of products. A promising direction in the development of industrial production is its digital transformation [1-4].

In the general case, digital transformation is understood as the implementation of digital solutions in the management and production business processes of an enterprise. This implementation, based on the use of digital technologies, causes qualitative changes in the activities of the enterprise. Optimization of production processes through the introduction of digital tools is the basis for
increasing the efficiency of the entire business and, as a result, the financial performance of the company [5-9].

The basic toolkit of digital productions is the creation of computerized workplaces based on the use of a cyber-physical systems (CCPS) that are embedded in a distributed integrated digital engineering environment of the enterprise [10-12].

The technical basis for digital transformation processes in production is the industrial “Internet of Things” (IoT) - a set of sensors and other “smart” elements that track business processes, from technological ones (obtaining data on temperature, pressure, and other characteristics of production processes) to ensuring safety (perimeter control, access control, video surveillance, identification, including biometric, etc.) [13-15].

Despite the obvious advantages of digitalization, most enterprises face a number of serious challenges when planning and implementing digital transformation. According to analysis of available literary sources, the main problems of the digital transformation of industrial enterprises are the high material costs of reorganizing the enterprise, the lack of necessary knowledge and skills among staff, and the immature digital culture of society. The problem with a lack of knowledge in the field of digital technologies and industries is being addressed by the organization of continuing education programs as part of the advanced training of enterprise personnel. The issues of improving the digital culture of society are decided by the organization of educational and educational programs at the state level [16]. Within a single enterprise, the most difficult and expensive problem is solving the problem of planning and implementing the processes of digitalization of production.

The development of tools for the formation and selection of the optimal program for the digital transformation of industrial enterprises is currently relevant.

The purpose of the work is developing methods and tools of the process of formation and selection of digital transformation programs for industrial enterprises, allowing to synthesize the whole set of possible solutions with the subsequent selection of the best based on a sound system of algorithms and preferences.

2. **Key method provisions**

The proposed method consists in presenting the structure of an industrial enterprise with weighted oriented graphs which determine the structure of a neural network, and its subsequent training on arrays of source information. Each hidden layer of the graph model determines any component of the production structure of the enterprise, and the neurons in them are the components of this structure. Consider the subject orientation of the hidden layers of the graph model [17-18].

In general, an industrial enterprise is a large complex dynamic system aimed at implementing a set of business ideas formed in accordance with the strategic development purpose. The enterprise management structure is formed from the relationships between the managing and managed subsystem. The main purpose of the managed subsystem of an industrial enterprise is implementing production activities. The production activity of the enterprise is organized for the implementation of a portfolio of orders of a certain technological complexity with specified levels of quality and productivity. As a part of this work, the digital transformation of the production activities of an industrial enterprise is considered in detail.

The initial information for the implementation of the production activities of an industrial enterprise is a dynamically developing specialized or diversified portfolio of production tasks that describes the range of products. Depending on the development of the market situation, the commodity nomenclature may be in a state of stabilization, modernization, innovation, and elimination (hidden layer $h_D$). The logical organization of layer $h_D$ is shown in Figure 1.

The enlarged production activity of the enterprise is determined by the technical preparation of production (hidden layer $h_T$), which characterizes the development of measures to improve the quality characteristics of products, the preparation and formation of a set of technical and technological means of automation of its manufacture; a set of technological processes for manufacturing products (hidden layer $h_{TP}$) based on the operation of equipment for technological operations; a complex of intra- and
non-production logistics activities that ensure the implementation of production tasks (hidden layer $h_L$).

As part of the digital transformation of an industrial enterprise, the basic structural units are a workstation (AWS) and a cyber-physical system (CCPS).

AWS is a complex of interconnected means of computing (hardware) equipment and software, located directly at the employee’s workplace. AWS destined to automate his work as part of the production task, aimed at implementation the inherent functions of forming the information flow, regardless of the impact of both internal and external factors embedded in the enterprise information system with use.

A cyber-physical system CCPS is a set of interconnected means of technical equipment for production operations, for example, production equipment, a computer control system, hardware and software for implementing and supporting production processes, designed to form material and information data streams.

Each AWS and CCPS are embedded in the enterprise information system using physical and logical connections. The logical organization of the hidden layers $h_T$, $h_{TP}$, $h_A$ and $h_C$ is presented in the form of a connected oriented graph (Figure 2). On the Figure 2 $v_1$, $v_2$, …, $v_p$ – neurons of classes of the hidden layers

The entire set of AWS and CCPS of the enterprise is divided into classes depending on the purpose (hidden layer $h_A$ and $h_C$, respectively). The interconnection of the functioning of layers A and K is carried out by a variety of “digital doubles” of production objects (hidden layer $h_{dd}$), represented by a set of virtual models obtained by numerical or statistical methods and characterizing their basic properties and state, according to $h_D$.

The sequential formation of the AWP and CCPS classes is carried out by passing tasks through the $h_{TP}$ layer, which combines the classes of production technologies.
The enterprise’s material flow system, represented by a set of internal and non-production logistics measures ensuring the implementation of production tasks (hidden layer $h_1$), is structurally represented by a material flow displacement matrix with calculation of the frequency of transport units per day.

Many possible options for digital transformation programs of an industrial enterprise are modeled by a set of workarounds for the graph formed by successive transitions between hidden layers from $h_D$ containing the initial information to the edge $h_{KPI}$ (hidden layer of KPI formation).

The selection of the optimal digital transformation program is carried out by estimating the weights of the graph workarounds using a set of KPIs performance indicators [19].

3. Method implementation

Implementation of the developed methodology is carried out on the example of formation virtual industrial enterprise transformation with a specialized portfolio of production tasks. The initial data of the model are databases of production facilities, technologies and production equipment for machine-building enterprises of the real sector of the economy.

To solve this problem, a multilayer connected neural network is formed. Neural network training is performed using an explicitly defined loss function. For the considered type of tasks, the loss function characterizes the quality of the ready-made solution and the state of the structural elements of the production system AWS and CCPS.

The loss function is defined in the multidimensional space which is defined by KPIs is differentiated to find the vector of the fastest change (gradient). To determine the contribution of specific neuron to the result of the loss function, is used backpropagation method which based on algorithms of deep learning which is a part of machine learning.

In the context of this task the backpropagation method allows determining the contribution of each neuron to the formation of the digital transformation program and KPIs.

The PyTorch library for the Python 3.8 programming language, which includes a module for constructing neural networks, an AutoGrad - partial derivation calculation module, and an nVidia CUDA - GPU parallel computing module, is used as the main tool for implementing the method. The software implementation of the methodology allows the formation of a neural network for the structure of an existing industrial enterprise and its modification both in the structure of layers and classes, and in the structure of neurons. To implement the procedure for modifying neurons developed an extension for the PyTorch library.

4. Conclusions

As a result of the research, the method for the formation and selection of digital transformation programs for an industrial enterprise is developed.

The basis of the methodology is the presentation of the structure of an industrial enterprise by weighted oriented graphs that determine the structure of a neural network, and its subsequent training on arrays of source information. Each hidden layer of the graph model determines any component of the production structure of the enterprise, and the neurons in them are the components of this structure.

The software implementation of the method is implemented in the Python 3.8 programming language and allows creating a neural network for the structure of an existing industrial enterprise and modify it both in the structure of layers and classes, and in the structure of neurons. To implement the procedure for modifying neurons, developed an extension for the PyTorch library.

The results of the research presented in the form of algorithms, models, and software, tested at existing enterprises in the real sector of the economy. Industrial testing of the methodology showed its efficiency in solving the problems of the formation and selection of digital transformation programs for industrial enterprises.

Further development of the method involves the optimization of machine learning algorithms, with the purpose of stabilizing the loss function to the requirements of production systems of various target values.
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