Information model of production and logistics systems of machine-building enterprises as the basis for the development and maintenance of their digital twins

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Abstract. The aims and tasks of the creating of digital twins of objects and processes have been considered. The aims and tasks of the development of the digital twin of the production and logistic system of the machine-building enterprise have been formulated. The structural model of the production and logistics system of digital twin has been offered and the data structure of the information model of the production and logistic system has been developed.

1. Creating of the digital twins of objects and systems

The development of the digital technologies in recent years is inextricably linked to the emergence of the new trends and approaches to the design and organization of production. An important transitional period was the emergency of the «Industry 4.0» concept. Its main idea is to is to digitalize production, increase the level of automation and change the role of man in production [1].

Development and production of competitive production of the new generation in the shortest possible time are possible with application of Factories of the Future – the systems of complex technology solutions, the main element of them becomes «smart» systems and Digital Twins of objects/products, production systems and process/production processes [2,3].

The concept of «Digital Twin» has many interpretations and definitions to date. The term was first introduced by Michael Grieves as a digital copy of a physical object or process [4,5]. Today, a digital twin is usually a virtual model of a real physical object or process, which is inherently a complex mathematical model that allows to describe with high accuracy the behavior of a real physical object or system, as well as a technological/production process or services. By using a digital twin, it is possible to concentrate the majority of changes and costs at the design stage, thus reducing the costs of the rest of the life cycle. In other words, a digital twin is a model of a real object or process that functions like its prototypes, while also using operational data on the current real state of operation. These models significantly enhance the ability to diagnose and predict complex systems By using a digital twin, it is possible to concentrate the majority of changes and costs at the design stage, thus reducing the costs of the rest of the life cycle. In other words, a digital twin is a model of a real object or process that functions like its prototypes, while also using operational data on the current real state of operation. Such models significantly expand the ability to diagnose and predict the operation of complex systems [6].
The construction of a digital twin is not limited to only collecting data read from a real object and thus only describing its current state. Such a data set defines the concept of a digital shadow of an object, which is a set of Big Data, taking into account the relationships and dependencies derived from the real object and describing its state, usually under normal operating conditions. It is believed that without the construction of a digital shadow of an object it is impossible to build its digital twin, but the digital twin must also possess the necessary set of laws and rules describing the behavior of the object and allowing to simulate its various states. Also, the digital twin must be able to determine and separate the content data cleared of debris and noise, while the digital shadow stores all readable parameters of the object or system. [3,7,8].

The construction of digital twins is a complex process that requires precisely recreating the behavior of an object or system, which is impossible in absolute form. The degree of proximity of the model to the real object forms the concept of adequacy of the digital twin, which can be determined by the number of parameters of the object taken into account, as well as the described logic and laws of behavior of the object [4,9,10].

Thus, even a simple description of an object, such as a drawing or 3D product model, is already in some way its digital twin, but with a low level of adequacy. It can also be noted that the level of adequacy will always be limited because it is impossible to fully describe any object, because its parameters exist an infinite set. However, you can specify a limited set of object parameters that are necessary and sufficient to solve a particular task.

Therefore, due to the complexity of a real machine-building enterprise, which includes subsystems of different nature: economic, legal, technological, constructive, operational, ergonomic, social, psychological, biological, etc., it is possible to speak only about the creation of a fragment of a digital twin based on an information model, including a limited set of data, facts, concepts or instructions, designed to meet a specific requirement [11,12].

Thus, depending on the requirements for digital twins, the same machine building enterprise may have several digital twins that contain appropriate information models describing different parameters and properties of the object and differ in the level of adequacy according to the specified requirements.

The main function of the machine-building enterprise is to manufacture products of a given nomenclature. This function is implemented in the production and logistics system and includes the following main types of logistics activities: material flow control and material flow conversion.

This paper deals with the creation of digital twins of production and logistics systems of machine-building enterprises, which are complex organizational and technical systems. Building a digital twin of the production and logistics system with the required level of adequacy will allow to fully assess its capabilities, current state, model various situations and scenarios of its functioning [2].

On the basis of the above, the creation of the digital twin of the production and logistics system of the machine-building enterprise is based on the development with a given degree of adequacy of an information model describing aspects of the functioning of its main subsystems in accordance with the aims and objectives solved by the digital twin.

2. Digital twin of production and logistics system of machine-building enterprises

According to the above approaches to the construction of digital twins [2,3,5], the main goal of creating a digital twin of the production and logistics system of the machine-building enterprise and the tasks solved by it, according to which the boundary conditions and degree of detail of the objects of the production system and the processes implemented in it are determined, was proposed.

The main aim of creating a digital twin of the production and logistics system of the machine-building enterprise is to develop a modern effective tool for calculation of parameters of production processes, analysis of organizational and technological capabilities of the production system, formation of solutions for execution of the production program and improvement of efficiency of production processes, as well as control of the production process taking into account the current production situation [13].
The digital twin solves the tasks of engineering activity and the tasks of operational activity. One of the most important duties of the digital twin is to provide an integrated solution to the problems of engineering and operational activities.

The composition of the tasks assigned to the digital twin of the production and logistics system, with the development of its role in the complex solution of engineering and operational tasks, will change [10,14].

However, it is already possible to identify a number of priority groups of tasks to be solved by the digital twin of the production and logistics system (Table 1).

Table 1. Main groups of tasks solved by the digital twin of the production and logistics system.

| Problems of engineering activity | Complete solution of tasks | Tasks of operating activities |
|----------------------------------|----------------------------|------------------------------|
| Design and technological preparation of production | - Balancing the workload. | - Development of production schedules. |
|                                   | - Calculation of production capacity required to fulfill the order portfolio. | - Formation of control actions on production and logistics system of machine-building enterprise. |
|                                   | - Simulation of production program execution. Analysis of results of modeling. | - Monitoring and dispatching of production processes and equipment status. |
|                                   | - Development of control solutions to reduce production cycles and manufacturing costs. | |
|                                   | - Risk assessment during the formation and execution of the release program. | |
|                                   | - Management of repair and maintenance system of engineering and process equipment. | |
|                                   | - Management of cooperation scheme and supply chains. | |

In accordance with the purpose of the digital twin of the production and logistics system of the machine-building enterprise, its structural model was proposed, which is shown in Figure 1.

Figure 1. Structural model of construction of digital twin of production and logistics system machine-building enterprise.
Build a digital twin of a production and logistics system of the machine-building enterprise is impossible without functioning information systems of the enterprises engaged in the coordinated management of production and business processes at various levels of management. The interaction of the digital twin with the material and technical objects of the production and logistics system of a machine-building enterprise (production level) is implemented by production management systems and operational and calendar planning systems, by generating production schedules and tasks. Feedback from the material and technical objects of the production and logistics system with its digital counterpart is carried out through production management systems or through monitoring and dispatching systems [15-18].

The amount of data and how often it is updated can vary greatly from one information system to another. From the systems that are part of the digital twin (Figure 1), we can distinguish such systems, the data in which can be considered conditionally constant (systems of technological preparation of production, enterprise management systems at the top level), systems with an average data update rate (systems of operational and calendar planning) and systems with a high data update rate-systems for collecting production data, diagnostics and monitoring. The total volume of all data in the existing enterprise information infrastructure is certainly very large, and the task of structuring and processing it can be attributed to Big Data technologies. But the implementation of a digital twin does not involve creating copies of data about the production and logistics system collected from all the information systems of the enterprise. The digital twin should combine information from different sources due to the built data structure and established connections between systems, while the information can remain in existing information systems. Moreover, the development of a digital twin implies the need to select and filter only meaningful data that is necessary and sufficient to solve specific tasks. Thus, the digital twin combines and connects existing information systems, is a kind of superstructure over the existing information environment of the enterprise and makes certain requirements for the available data, as well as for additional data in their absence [2,17].

The digital twin can be implemented by creating an information model that interacts with enterprise information systems through application programming interfaces (API), allowing the collection and aggregation of the necessary up-to-date data on the operation of the production and logistics system in order to synchronously represent the state, operating conditions and configuration thereof. The information model should include a limited set of interrelated data, facts, concepts or instructions, necessary and sufficient to solve problems in the field of management and transformation of material flow [16,19-20].

In general, the production and logistics system can be described by its two main functions: material flow control and material flow transformation. The data structure of the production and logistics system information model of the machine-building enterprise includes two main data units:

- Data unit for generation of control actions, designed for information support of material flow control processes;
- A data block that defines the material flow and the rules and resources to convert it.

Material flow can be described with three main elements: products, processes, and resources. A product is any material object whose state changes during the manufacturing process and which results from the manufacturing process (material, workpiece, part, product). Processes include manufacturing processes including process, transportation, quality control and testing, maintenance and repair processes, etc. Resources include all production facilities of the enterprise (equipment, technological equipment, production infrastructure, human resources, transport and storage equipment, information infrastructure, etc.) [14,19].

The data set required for analysis, evaluation, and simulation systems is often generated once at a certain time interval. This is due to the difficulty of collecting information from various information systems and bringing them into the required format. The description of a one-stage condition of production and logistics system in which changes happen in real time, such as change of the schedule, change of structure and condition of resources, etc. are not considered is in that case formed. In order to solve this problem related to information support of assessment and analysis systems, it is proposed
to create local information models containing only data necessary for solving a certain task or group of tasks. These local information models are created each time to perform the corresponding tasks based on requests from evaluation, analysis and modeling systems by aggregating information from various systems in accordance with the specified links contained in the information model of the production and logistics system [13].

The generalized type of data structure of the information model of the production and logistics system of the machine-building enterprise required to solve the proposed tasks (Table 1), as well as the sources of obtaining these data are presented in Table 2.

### Table 2. Data structure of the information model of the production and logistics system of the machine-building enterprise.

| Information model structural elements | Data unit for generation of control actions | A data block that defines the material flow, rules, and resources to convert it | Description of referenced data groups | The names of the systems which are linked to the digital twin of production and logistics systems |
|---------------------------------------|---------------------------------------------|----------------------------------------------------------------------|-------------------------------------|-----------------------------------------------|
| Information model of production and logistics system of machine-building enterprise | Product item data group | Production process data group | Production resource data group | Manufacturing Process Management Systems (APS, MES) |
| - Portfolio, production program data; - Performance indicators of the cooperative scheme, performance targets (KPI) | - Design and process parameters of nomenclature items; - Design documentation | - Description of technological processes, transportation processes, as well as references to necessary technological resources, process stability indicators. - Description of process equipment maintenance and repair processes | - Composition of available technological resources, indicators of their availability, indicators of reliability. - Description of resource utilization and storage values of work in progress | - Monitoring and dispatching systems (SCADA, MDC, MDA) |
| - Manufacturing Process Management Systems (PDM, CAD/CAE, CAM/CAPP) | - Process Preparation and PLM Systems (PDM, CAD/CAE, CAM/CAPP) | - Process Preparation and PLM Systems (PDM, CAD/CAE, CAM/CAPP) | - ERP Systems | - Monitoring and dispatching systems (SCADA, MDC, MDA) |
| - Monitoring and dispatching systems (SCADA, MDC, MDA) |

The production and logistics system of information model comprises data having a formal description, i.e., for a machine-oriented description, and data not having a formal description for human processing.

In the process of developing the role of the digital twin of the production and logistics system in the complex solution of engineering and operational tasks, the degree of their automation will increase. The proportion of data having a formal description will also grow [17,20].

### 3. Conclusion

Thus, it is not possible to solve the problems of analysis, simulation, assessment, forecasting and control of the production and logistics system without the availability of coherent, logically connected source data about it, which can be solved by the development of a digital twin of the production and logistics system.

The development and maintenance of the digital twin of the production and logistics system is carried out on the basis of its information model, which determines the requirements to the structure of data necessary for solving the corresponding tasks, processes of their updating and, therefore, to the composition and interaction of information systems containing and processing this data.
Proposed method of information support of tasks solved by digital twin will allow to quickly form corresponding local information models containing up-to-date data on production and logistics system of machine-building enterprise.

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