Application of simulation methods to optimize the composition of technological complexes of machines

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Abstract. The paper proposes a method for determining the optimal parameters of technological systems in environmental management, based on the principles of automated support for organizational decision-making during the formation of production structures and effective technological complexes of machines. The technique is based on simulation modeling of various options for the implementation of the process using a multi-agent approach

Production processes in environmental management are complex dynamic systems, accompanied by the influence of many external and internal factors of probabilistic nature. To ensure effective implementation of the selected structure of the production process it is necessary to consider features of both the technological process and features of functioning of its individual elements – tehnologicheskih systems and complexes, including the production of technical operation of means of mechanization [1].

High economic efficiency of functioning of existing and newly created objects of production activity in environmental management can be provided only in the case of rational distribution and use of material and technical resources of the enterprise at all stages of technological processes, which is quite difficult to implement in practice. The solution of this question includes the account of action of a set of probabilistic factors concerning each technological element of process influencing as a whole all production activity of the enterprise and as a whole on its efficiency.

One of the possible tools in the process of organizing effective production structures can be a progressive approach based on intelligent systems of information support of production processes. As a rule, representatives of this segment of information systems and technologies are based on various methods of computer modeling of the studied dynamic processes.

At the same time, in many spheres of human activity there is a class of such objects for which, for various reasons, analytical models have not been developed, or methods for solving the resulting model have not been developed, or the developed models are not

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suitable for conducting effective computational experiments. In this case, the mathematical model is replaced by a simulation model.

Simulation modeling is the development and execution on a computer of specialized software functionality that reflects the structure and behavior of the simulated object or phenomenon in time. The software package obtained in this case is called a simulation model of the object or phenomenon. A simulation model is a simplified representation of a real system, either existing or intended to be created. In simulation modeling the following main types can be distinguished: dynamic systems, system dynamics, discrete-event modeling, agent modeling [2]. Mathematically, system dynamics and dynamical systems operate mainly with time-continuous processes, whereas discrete – event modeling and agent-based modeling operate mainly with discrete processes.

In discrete-event modeling, the functioning of the system is represented as a chronological sequence of events. This approach is based on the concept of requisitions, resources, and flowcharts that define requisition flows and resource utilization. The event occurs at a certain point in time and causes a change in the state of the system. Applications are in the queue, obrabatyval, capturing and freeing resources, dividing, connecting, etc. Discrete-event model can be seen as a global scheme for processing of applications, typically with stochastic elements [3]. Unlike system dynamics and discrete-event models, agent models are decentralized. It does not determine the behavior of the system as a whole, the behavior of agents is determined at the individual level, and the dynamics of the system arises as a result of the activities of many agents.

Multi-agent modeling is a more versatile and powerful approach because it allows you to account for any complex structures and behaviors. Another important advantage of multi-agent modeling is that the development of the model is possible in the absence of knowledge about global dependencies: it is necessary to determine the individual logic of the behavior of the process participants in order to build a multi-agent model and derive from it the nature of the global behavior of the entire system. Multi-agent systems are used to create a wide range of information systems, besides the multi-agent model is easier to maintain: refinements are usually made at the local level and do not require global changes.

The key concept in multi-agent systems is agent. This concept is used in many areas of application and system programming. Also, this concept is the main one in the field of artificial intelligence and distributed intelligent systems [4].

Taking into account the totality of parameters and acting factors, as well as the effects of a combination of different parameters and event probabilities, it is possible to describe a technological system of any complexity.

The use of multi-agent technologies from the design point of view makes it possible to move from the classical modeling method using one complex and cumbersome algorithm to many simple ones. An important advantage of this technology is the unloading of the General program code, which results in a significant increase in the speed of calculations.

To develop a multi-agent simulation model it is necessary to adhere to the following basic rules:

1. A model is a collection of agents;
2. An agent has a set of properties that are similar to the most important properties of a real object;
3. There is a set of rules that characterize the interaction of agents between themselves and the environment.

One of the key features of the application of this technique in creating a simulation model is to obtain a unique dynamic program code that gives the model a number of properties, of which the most important is the adaptability of the system. This property allows to improve the quality of simulation of the process under consideration, due to the most effective adjustment of the degree of influence of difficult to formalize factors formed by the interaction of the system environment and process participants.

The General view of functional description of interaction of elements of technological system in the field of environmental management has the description:

$$S=\{t,c,x,q,y,\varphi,\beta\}\ , \quad (1)$$

where t – is the region of time periods; c – is the set of possible input perturbations; x – is the set of instantaneous values of the input perturbations; q – set of states; y – set of values of output quantities; φ – transition function of system state; β – system response.

Reduced cost for implementation of the mechanized works and prediction of possible losses when using different variants of technology of work and operating conditions of machines allows to increase the income of the enterprise through the use of the most effective combinations of parameters of technological elements of machines during the execution of technological processes [5].

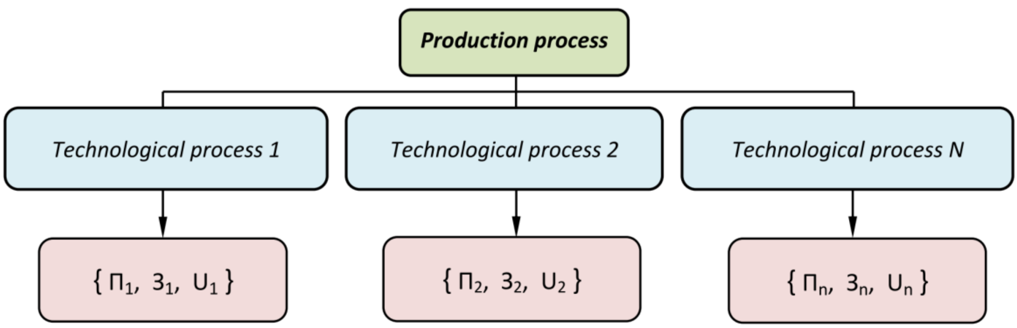

Fig. 1. General view of the structure of the production process

$$I = \sum_N (\Pi_i - З_i - U_i)\ , \quad (2)$$

where I – is the total income from the activities of the enterprise; N – number of technological processes; Π_i – funds allocated for works; $З_i$ – costs for implementation of works; U_i – the amount of damage caused by the disruption of the production process.

The construction of multi-agent models requires the definition of a set of agents and the foundations of their behavior, the definition of relationships between agents and the theoretical foundations of these relations, the choice of a platform for multi-agent modeling [6].

Traditional simulation approaches treat modeling objects as arithmetic averages or as passive applications or resources in the process. These methods do not take into account the individual characteristics of each of the simulated objects. At the same time, it is precisely because of these features that the dynamics of the whole system can change. Agent modeling does not have these drawbacks, it considers objects as active, interacting elements that can exhibit individual properties. For this reason, agent-based modeling can be considered the most realistic method of studying complex systems, allowing to recreate the most likely scenarios of their behavior.

The stages of creating a multi-agent simulation model are performed based on compliance with the proposed rules according to the standard methodology for developing simulation models presented in Fig.2.

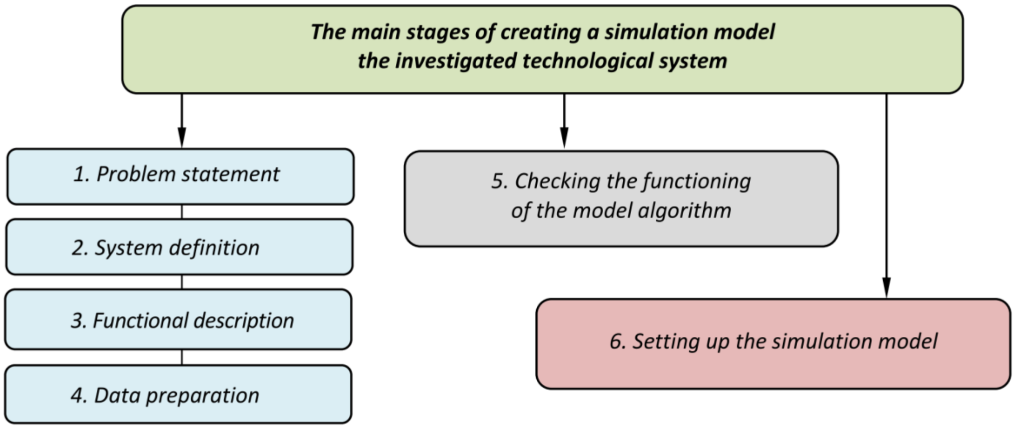

Fig. 2. Stages of creation of simulation model of technological system

1. Problem statement. Determination of the main technical and economic indicators of the results of the operation of the technological system using the available input data under specified conditions.

In the process of development, a model of the technological system is created, which is able to accurately reflect the properties of the real system and its elements in the modeling process. According to the results of the calculations of the model, it is necessary to implement the functionality that allows to collect, process and translate data into the information and reference module.

2. System definition – description of mandatory unregulated parameters of the process, determined by the environment of the technological system.

All types of work in the field of environmental management have a number of regulatory, agrotechnical, environmental requirements and restrictions. In this regard, there is a need to take into account these circumstances in the simulation model in order to give the most realistic properties of the simulated objects.

3. Functional description. Determination of functional interrelations between elements of the considered technological system is carried out on the basis of the system approach according to the offered technique and application of methodology of functional modeling of IDEF0.

4. Data preparation. Determination of the main parameters that have a significant impact on the process of functioning of the technological system, manifested at one or more stages of simulation. Such parameters must be identified and formalized in order to correctly account for the proposed system of certification of elements of the technological system. These parameters may include: operational and technological characteristics of technological machines, the order of operations, climatic properties of the environment, etc.

5. Checking the functioning of the model algorithm. The next stage of creating a simulation model is to check the functioning of the program code, which is performed by means of trial runs of the process simulation and monitoring of changes in the values of variables simulating functional relationships.

Verification of the correct functioning of the parameters entered into the model begins with the definition of simple functional relationships and ends with the evaluation of the functioning of the entire system as a whole.

In the process of model programming, it is necessary to take into account the peculiarities of interaction of the technological system with the environment and all its subsystems, including the subsystem of the technological process, resource support and control subsystem.

Translation of the knowledge accumulated in the course of research into the simulation environment can be implemented through the use of modeling tools from the available libraries of the simulation environment.

To describe the main components of the studied process, it is possible to use several types of modeling offered by the developers, combined in one functioning environment, based on the rules of creating multi-agent systems [7].

In General, the function of the control subsystem is to distribute the machine agents on the currently demanded operations. The applied algorithms are implemented in the form of separate independent programs (agent or system elements), which have the ability to interact with each other.The behavior of agents is regulated by the General algorithm of the technological process based on the rules laid down in the control subsystem. Each machine, like an operation, has a certain priority to perform the work. In the event of an emergency situation, for example, associated with technical or technological downtime, such an algorithm will partially restore the functioning of the system by transferring resources to areas that have lost productivity and inhibit the functioning of the entire system.

The composition of the algorithms of the system elements in conjunction with the algorithm of the control subsystem in the presented form has the right to be considered an intellectual component of a multi-agent system. Its presence in the model allows you to fully adjust the situation possible in real production, adjusting the adaptability of the system by inserting statistical data taken from the real system into the model. Such data should also include time for decision – making in the event of an emergency situation and other events of an organizational nature. Refinement of these parameters is performed at the stages of model configuration [8].

In General, the interaction of the considered subsystems, taking into account all the limitations defined in the process of preparation and collection of statistics, allows to achieve the most effective modeling of the production process. After making a series of runs of the model and making sure that the functional connections obtained during the test highly reflect the real processes corresponding to the system under consideration, a decision is made to conduct an experiment that reflects the parameters of the real technological process and perform the final stage of creating the model.

6. Set up the simulation model. The final stage of creating a simulation model is to check its adequacy and accuracy. Adequacy assessment is a stage of conformity assessment of the obtained simulation results with field studies to make a decision on the use of the model or its adjustment.

To check the adequacy of the developed model, the variance of deviations of the simulation results and available statistical data on the operation of the complex in real operation is evaluated.

The model is considered to be adequate when executing the expression:

$$y_f \in [y_{mod} - t_\alpha \cdot \sigma_{mod};\ y_{mod} + t_\alpha \cdot \sigma_{mod}], \quad \text{by } x_{mod} = x_f \ , \qquad (3)$$

where y_f, y_{mod} – the result of a real system and a simulated one respectively; x_f, x_{mod} – input data of real system and simulated system respectively; t_α – Student criterion; σ_{mod} – standard deviation of the simulated parameters.

To complete the setup of the simulation model, an additional assessment of the available statistical data on all stochastic values available in the calculations is made and, if possible, the law of their distribution is specified, which is subsequently entered into the model and the electronic passport of the corresponding agent. It should be noted that the addition of more accurate laws of distribution of random variables, slightly affecting the process of functioning of the model, does not always have a positive impact on the effectiveness of its further application.

In cases where the model is initially overloaded or there is an excessive description of factors that slightly affect the accuracy of the model, the researcher decides to reduce the number of factors taken into account by combining them into groups or reducing the ranges of variation of the stochastic value to a specific, usually average value.

Modeling of the considered technological process does not allow to adjust the model immediately, since the value obtained at the end of the simulation is random. To solve problems with the presence of random variables, the Monte Carlo simulation method has proven itself well, the use of which has a number of features and technological advantages, including the possibility of organizing high-performance computing, which contributes to improving the accuracy of modeling of the studied technological systems [9].

In General, we can say that in recent years, information systems have become so complex, and the class of tasks so extensive-that the construction of a multifunctional system becomes impractical, costly and time-consuming, and the change of any task will certainly lead to the need to process the system or its individual modules. It is much more technological to build a system of agents in which each agent, even if it is less perfect than the system as a whole, will be focused on its field, and to solve complex problems, agents will cooperate depending on their goals and capabilities.

Thus, the use of modern simulation methods in the field of optimization of technological systems allows you to predict cost reduction in the implementation of mechanized operations and to consider possible losses when using different options of the technology of the work and operating conditions of complex machines, which can increase the income of the enterprise through the use of the most effective combinations of parameters of technological elements of machines during the implementation process [10].

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