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RESEARCH OF THE SYNCHRONOUS WAVEN COORDINATION MODEL OF PRODUCTION PROCESSES

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Abstract*. In the article the model of one-level coordination of production processes is created and indicators of wave synchronous coordination algorithm are investigated. It is shown that in case of high complexity and fast reaction of elements to random perturbations, the case is possible when the required period of initiation of the coordination wave becomes less than the wave propagation through the system, i.e. the coordination time.*

Анотація*. У статті створено модель однорівневої координації виробничих процесів та досліджено показники алгоритму синхронної координації хвиль. Показано, що у випадку високої складності та швидкої реакції елементів на випадкові збурення можливий випадок, коли необхідний період ініціації координаційної хвилі стає меншим за поширення хвилі через систему, тобто час координації.*

Keywords: synchronous waven algorithm, production processes, one-level coordination
Ключові слова: алгоритм синхронної хвилі, виробничі процеси, однорівнева координація

Introduction

The complications and rapid development of distributed control systems (DCS) have especially accelerated with the cheapening and micro-miniaturization of microcontrollers. It became possible to include microcontrollers in the field-level sensors and actuators. On the other hand, communication systems are developing at a rapid pace. From these two fundamental advances, the Internet of Things (IoT) was born, which in turn has pushed new research into the well-known problem of production processes coordination. After all, a large number of local "microsystems" of control requires their coordination within the automated control system. The class of processes that have the problem of coordinating decisions is characterized by the simultaneous execution of several technological operations, and operations can be performed sequentially in a continuous flow, or in parallel with the allocation of resources.

In the classic work [1] mathematical models of hierarchical structures of management are investigated. Subsequently, the coordination problem was considered explicitly or not for hierarchical systems [2-6].

In their work, the authors also investigated the problem of coordination with respect to hierarchical systems of process control [7-11]

However, with the development of cloud technology and parallel programming capabilities, multi-agent systems are becoming increasingly popular. For such systems, coordination problems have certain features [12, 13]

Hierarchical principles of coordination may also be used in multiagent systems, but methods of single-level coordination are of particular interest. Investigation of the influence of the characteristics of the controlled system on the indicators of single-level coordination is an important task in the problem of construction of such systems.

The aim of the research is to create a model of single-level coordination of production processes and to study the indices of the wave synchronous coordination algorithm.

Model of single-level coordination

To build a model of single-level coordination, we will submit a controlled system in the form of two graphs:

1. Flow graph $G_F(S,X)$, where S is the set of local subsystems; X is the set of flows (material, energy, information) between the controlled subsystems' objects. Each element of the flow set is a vector whose components characterize the individual products of the multi-product subsystem. Each subsystem consists of a controlled entity and a local control subsystem (LCS). Parameters of subsystem are specified by local coordinators, which interact to coordinate. Thus, the node of the flow graph has the structure shown in Fig. 1;

2. Process graph $G_P(X,Q)$ in which the flows X are the set of vertices and the edges Q represent the activity of local subsystems and are characterized by a triple $\{v,q,\tau\}$, where v is the quantity of the product; q is the product quality; τ is the time of the production.

3. Flow and process graphs are dual in structure, but the use of two types of graphs allows you to concentrate all the information you need in the weights of the edges.

Accordingly, the coordination model is implemented in the form of N objects, models of individual subsystems that exchange messages according to the flow and process graphs of the system. The object class diagram is shown in Fig. 2.

From the class diagram it is evident that in order to implement the model it is necessary to define:

- Structure - flow and process graphs;
- Impact vectors;
- Production functions of the elements;

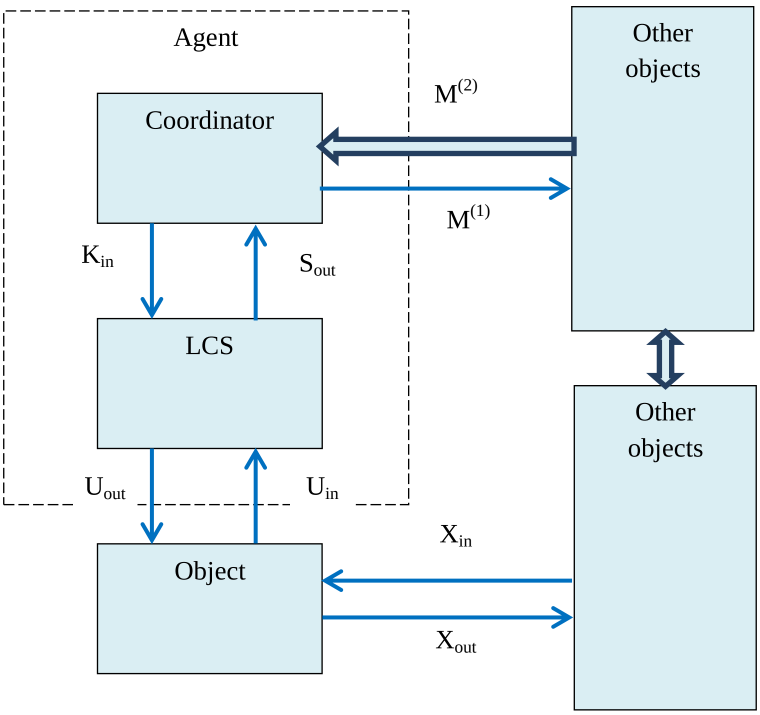

Fig. 1 – Object model

- LCS transfer functions;
- Element coordination functions;
- Coordination marker reception and transmission functions;
- Separate and general criteria.

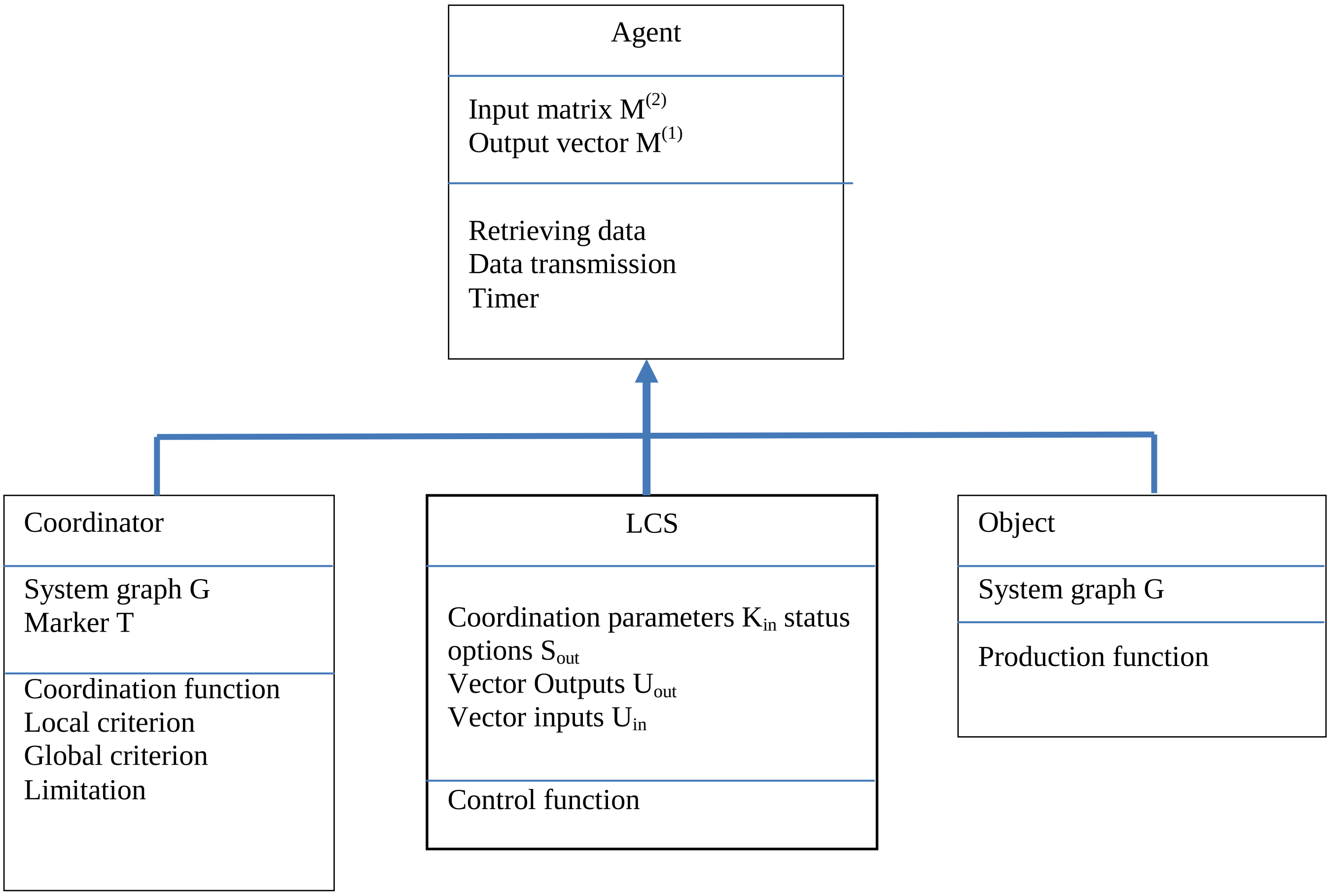

Fig. 2 – Class diagram

The content of the coordination function is represented in the activity diagram in Fig. 3.

The coordination function is implemented on the basis of a synchronous wave algorithm. Synchronization is ensured by binding the start of the algorithm to the internal timer clock signals. Since modern computer systems and networks have timers using world time, the use of internal (local) timers provides better synchronization than transmitting to agents in a cloud of a separate synchro-signal.

The wave coordination mode is provided by the transfer of a marker to initiate the coordination function from one agent to another. The transfer is made to the agents according to the production process graph. Identification of the destination agents of the token is carried out by means of a "wide search". In order to provide directional wave propagation, the markers are numbered and the coordination function is activated only when a new marker is received. The first wave begins with the START signal transmitted through the web interface, from the final operation of the production process Q_F and propagates to the initial operation Q_S , then from the initial to the final operation, and so on to receive the STOP signal.

Coordination parameters are determined using multicriteria constraint optimization.

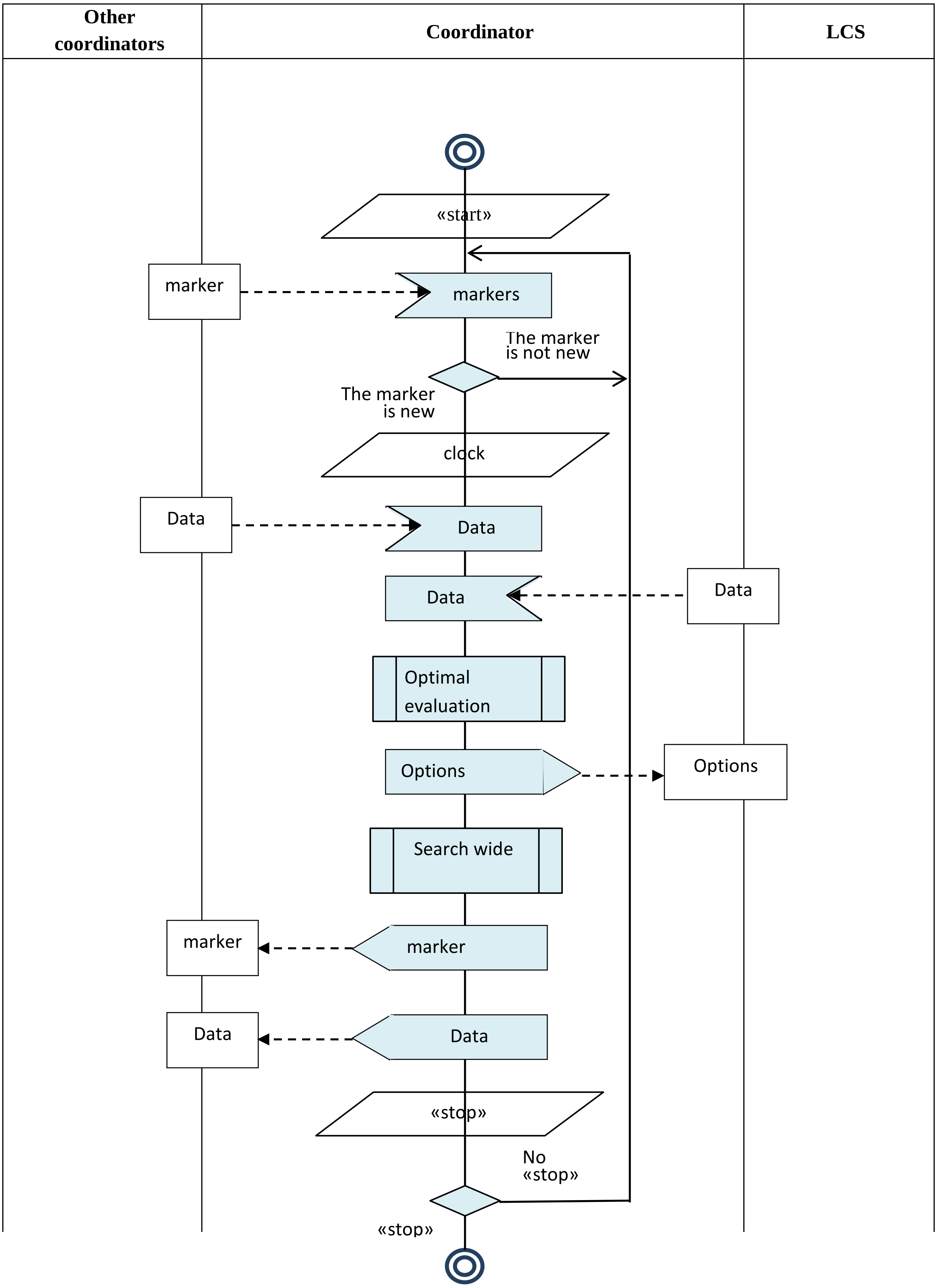

Fig. 3 – Activity diagram

The simulation process is controlled through the web interface, which diagram is shown in Fig. 4.
In determining the indices of single-level wave coordination, we will proceed from the following.

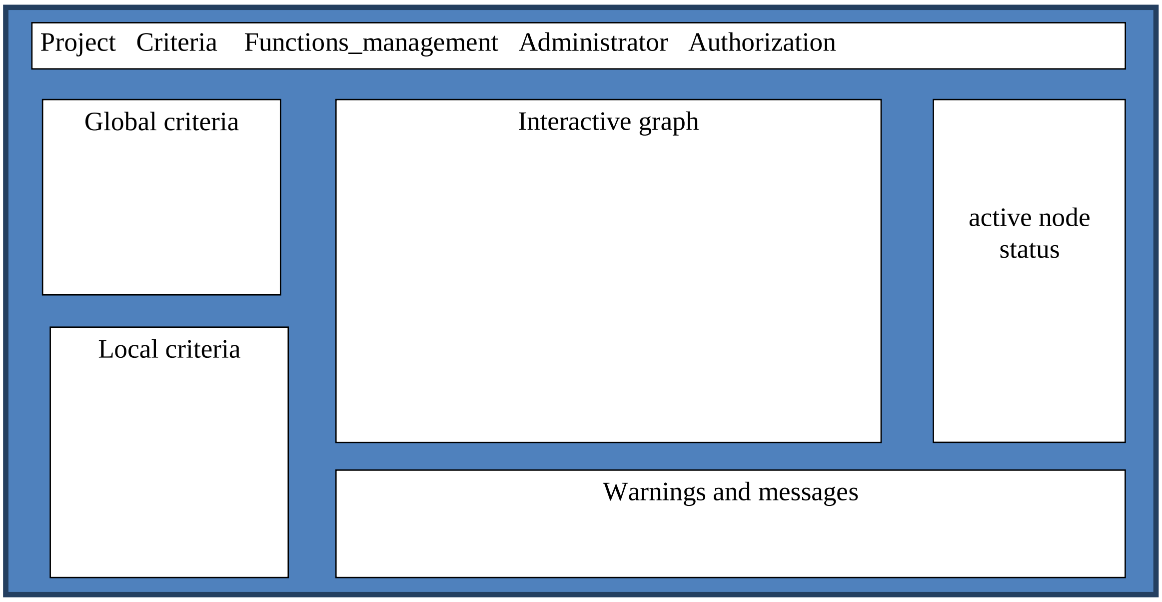

Fig. 4 – Web interface

1. We will treat the production object as a nonlinear dynamic system is shown on Fig.5 where $f(X)$ is the nonlinear part of the production function; X - vector of resources; Z_1, Z_2 - external influence vectors on system parameters $W(p)$ - transfer function of linear dynamic part of the production function.

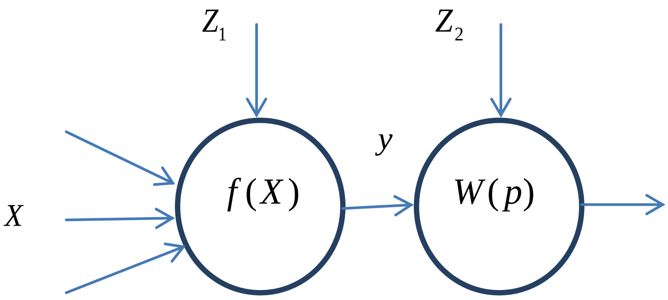

Fig. 5 – Production object as a nonlinear dynamic system

2. Production function.

In previous works, the authors considered the processes in systems with relay control [14]. It has been shown that there is an oscillatory process in such systems, which can be approximated by segments of production functions of logistic type.

We use the most common logistic function as a production function

$$f(x) = \frac{1+\beta}{1+e^{-\alpha(x-x_0)}} - \beta, \quad (1)$$

where x is the input resource; x_0 is the nominal amount of the resource; α –and β are the parameters of production, moreover $\alpha > 0$, $\beta < 1$ and $\frac{1+\beta}{1+e^{\alpha x_0}} - \beta = 0$ when $x = 0$, from where $x_0 = -\frac{1}{\alpha}\ln(\beta)$.

Let's take a dynamic component of a production function of a typical sigmoid form, which corresponds to a 2-order transfer function

$$W(p)=\frac{1}{T_2^2 p^2+T_1 p+1}. \tag{2}$$

If a production function uses more than one resource (the dimension of the resource vector > 1), then the quantity of the product is determined by x_i, which is the least resource

$$i=\hat{i}\rightarrow x_{\hat{i}}=\min_i\left[\frac{1+\beta}{1+e^{-\alpha(x_i-x_{i0})}}\right]. \tag{3}$$

3. Definition of local criterion

As a local criterion, we use the economic indicator - profit from the operation of the system $P=I-C$, where P is the profit; I is the revenue; C are the cost.

The cost consists of the costs of all the resources that come to the object,

$$C=\sum_{i=1}^{n} c_i x_i , \tag{4}$$

where c_i is the cost of the i-th resource; x_i is the amount of the i-th resource.

Revenue is proportional to the amount of the object's product

$$I=c_y y=c_y\left[\frac{1+\beta}{1+e^{-\alpha\left(x_{\hat{i}}-x_{\hat{i}0}\right)}}-\beta\right]. \tag{5}$$

For this model we neglect the dependence of the price of the product c_y on its quality q_y and the dependence of the quantity and quality of the product on the quality of resources q_i. Such neglect is permissible only for production processes without cycles, since cyclicality implies a gradual improvement of product quality at each cycle, which is crucial for such processes [15].

The local criterion can be negative if it is necessary to achieve the global goal of the system. In the case of successive production operations, the products of the previous operation are the next resource, therefore

$$I_i=C_{i+1}. \tag{6}$$

4. Definition of the global criterion

The global criterion characterizes the performance of the system in general

$$P_g=I_F-\sum_{o=1}^{M} C_o , \tag{7}$$

where P_g - profit from the output products of the system, I_F - revenue from the production of the system, which is the income of the final operation; C_o - external resources consumed by the system.

5. Transfer functions of LCS

Fig. 6 shows the LCS structure and the input effects: u_α - control influence from the coordinator; z_α - disturbing external influence. LCS ensures that the necessary values of the production function parameters are maintained: α, β, T_1, T_2. In our model, we will use a linear proportional-integral law (PI) for each parameter.

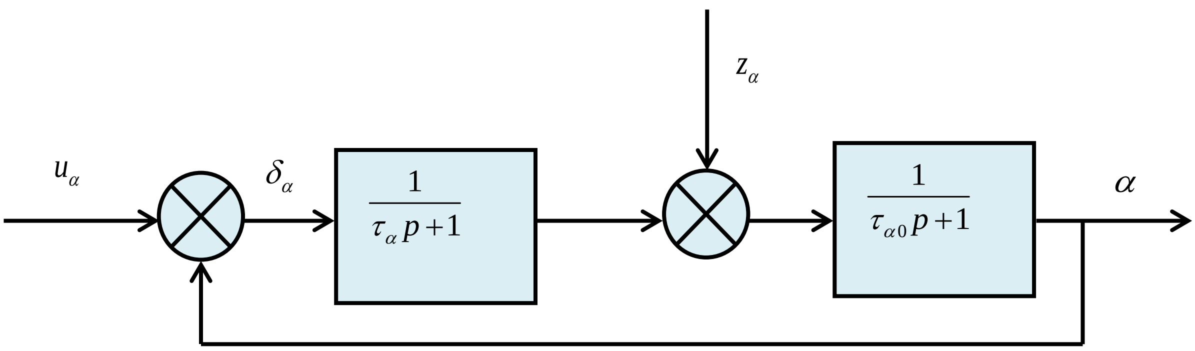

Fig. 6 – LCS structure and the input effects

The operator model of such LCS

$$\alpha = u_\alpha \frac{1}{1+(\tau_\alpha p+1)\cdot(\tau_{\alpha 0} p+1)} + z_\alpha \frac{\tau_\alpha p+1}{1+(\tau_\alpha p+1)\cdot(\tau_{\alpha 0} p+1)}. \quad (8)$$

6. Optimal evaluation.

The LCS parameters in the coordination algorithm are found by the estimation method, which is to find the optimal parameter value that provide the maximum of the coordination criterion.

The results obtained

As a result of simulation with the model is being described, the following dependencies are analyzed:

- The dependence of criteria on the system complexity (Fig. 7).

The complexity of the system M, in the case of assumptions are being made above about the same representation of a production functions, will depend only on the complexity of the graph structure. Since the flow and process graphs are dual, the complexity can be determined by any of them. Therefore, as a characteristic of complexity, we will use a cyclomatic number [16]. For a graph without cycles $M = \sum_{\forall X} n_X - m_S$, where n_X is the dimension of the flow vector X, m_S is the number of subsystems (processes). The maximum value of the criterion is observed in full coordination, the minimum value in its absence.

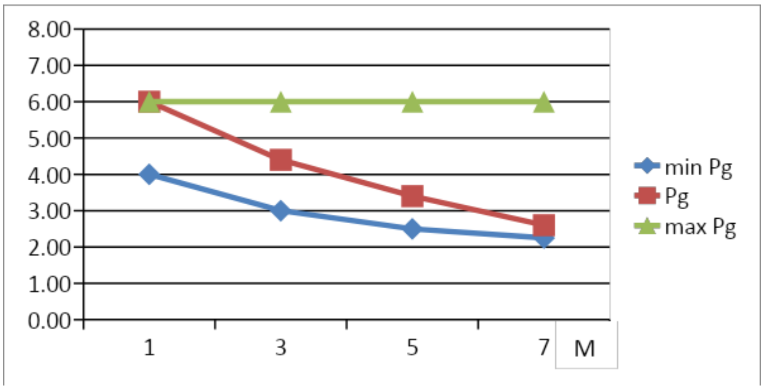

Fig. 7 – The dependence of criteria on the system complexity

- The dependence of criteria on the coordination period (Fig. 8).

The coordination period T is measured by the relations T/T_1 and T/τ, where T_1 is the time of the dynamic component of the production function, τ is the correlation interval of random perturbations (on the plot they are $T1$ and t, respectively).

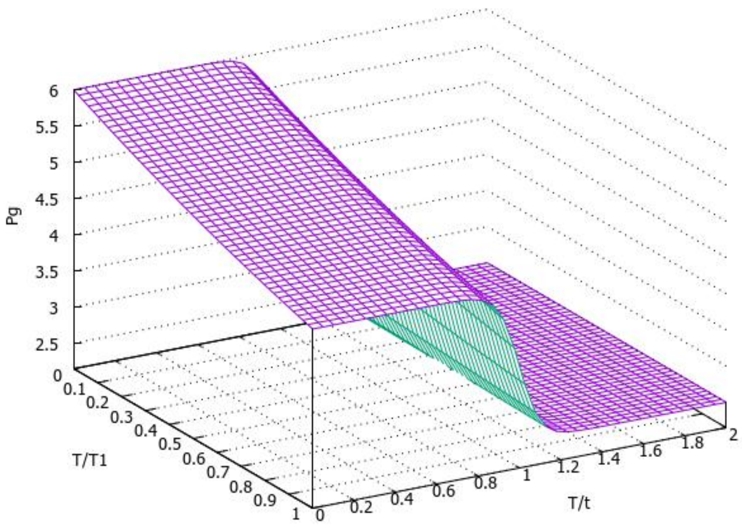

Fig. 8 – The dependence of criteria on the coordination period

- The dependence of criteria on the number of coordination waves and system complexity (Fig. 9).

On the Fig. 9, the number of coordination waves is being signed as k. Although the graph was constructed for the number of coordination waves $0 < k < 10$, results were stabilized after 5 waves.

Analysis of results

The dependence of the criterion on the complexity of the system, is being shown in Fig. 7, points out that with increasing complexity and constant parameters of the elements of the system, the coordination criterion decreases from the maximum value due to the parameters of the coordination system, and tends to a minimum, which corresponds to a complete uncoordinated one.

The dependence of the criterion on the time characteristics of the system (the ratio of the coordination period to the time constant of the dynamic component of the production function and the interval of correlation of random perturbations), is being shown in Fig. 8, points out that $T > \tau$, where τ is the interval of correlation of perturbations, the coordination efficiency decrease sharply, while the inertia of the system elements is less affected and the criterion decreases more slowly.

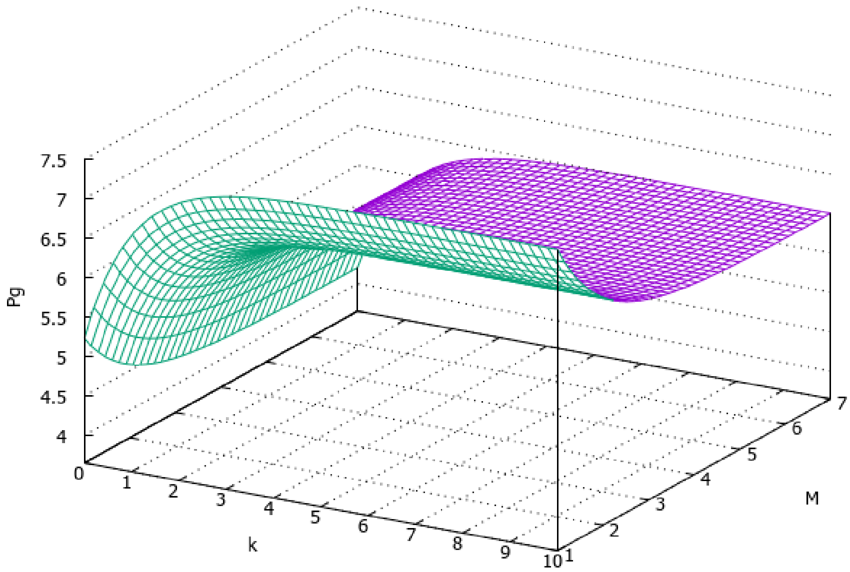

Fig. 9 – The dependence of criteria on the number of coordination waves and system complexity

The dependence of the criterion on the number of coordination waves at different system complexity, is being shown in Fig. 9, points out that as the complexity increases, the coordination efficiency decreases, but the coordination algorithm reaches the established efficiency value faster by averaging a large number of random effects on the system.

Conclusions

The study of single-level coordination wave algorithm on the simulation model showed its efficiency, but when determining the coordination period, the complexity of the system and the inertia of its elements should be taken into account. With high complexity and rapid response of elements to random perturbations, it is possible that the required period of initiation of the coordination wave will be less than the time the wave travels through the system, that is, the coordination time. This requires some modification of the algorithm.

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АЛГОРИТМІЗАЦІЯ ШИФРУВАННЯ ЦИФРОГО ПІДПИСУ

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