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COORDINATED AUTOMATIZED CONTROL OF AN ORE-PROCESSING ENTERPRISE AS A TECHNICAL-ORGANIZATIONAL SYSTEM

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Abstract:. *The primary objective* of the paper is to develop a method of automatized control of ore-preparation and oredressing technological processes at the ore-dressing and processing enterprise, whose structural units have their own preferences in relation to technological and organizational processes.

The *methods* for achieving this objective are as follows: analysis of domestic and foreign experience, systematization of available approaches and methods, methods of numerical simulation for synthesis and analysis of mathematical model, methods of mathematical statistics and probability theory for processing the results of experiments, methods of analytical design and computer simulation in the synthesis and analysis of control system, methods of system analysis in the development of control algorithms.

The scientific novelty is in the method of coordinated automatized control of the ore-processing enterprise as a technicalorganizational system consisting of agent and agent-controlled technological process, both of which have fixed operation technology. Rational behavior of technical-organizational system participant under consideration is to minimize their own costs taking into account all available information about technological and organizational processes.

Stressing the *practical significance* of the study, it was thus suggested to improve efficiency of the enterprise as a whole, as well as its certain structural elements including a control center, a mine, a crushing plant, an ore dressing plant.

Results. The research sets out the results of the investigated approach to ore-dressing process control at the ore-dressing enterprise as a technical-organizational system in market economy terms with a view of activity and own preferences of structural elements of the ore-dressing enterprise. The automatized control process of technical-organizational system “control center – oredressing plant” was considered and general optimization model with restrictions was proposed. Simulation analysis makes it possible to conclude that the proposed approach of organizational and technical production management in the mining and processing operations allows to improve the control quality.

Key words: coordinated control, automation, ore-dressing, technical-organizational system.

Introduction. One of the crucial aspects of effective automatized control of large industrial enterprises, for instance, an ore-dressing and processing enterprise is to provide optimal performance both for the enterprise as a whole and its certain structural elements such as a control center, a mine, a crushing plant, a processing plant.

A large industrial enterprise should be viewed as a technical-organizational system in order to address the issue more effectively. Oreprocessing technological processes and organizational interaction of individual structural units are used as a basis in designing an automatized control of such systems.

Materials and methods

1. Analysis of problem solving state

Methods of automatized control of orepreparation and ore-dressing technological processes at ore-dressing and processing enterprise, based on classical approaches and intelligent control theory, are developed in [1-7]. Analysis of these works suggests that for improving automatized control efficiency of orepreparation and ore-dressing technological complex it is necessary to take into account such factors as technological types ratio of processed ore and behavior of enterprise organizational processes – activity of its units.

Control mechanisms of active system with a focus on organizational component of production processes subject to human factor are considered in papers [8-10]. In general, task of active system automatized control is described as follows.

In model constructing, control process is considered from the standpoint of control center [9]. Consequently, it is necessary to describe control center preferences and consider its decision making model under interaction with specified units (agents).

Agent and agent-controlled technological process have fixed operation technology. Dependence w(·) of activity result on action and conditions is considered to be known to all participants of technical-organizational system (TOS) and cannot be changed [9]. Changing technology w(·) of agent-controlled technological process as a passive object can be solved by methods of classical control theory. Agent preferences on set of possible performance are specified by its utility function v(·), and activity result $z \in A_0$ depends on action $y \in A$ and conditions $\theta \in \Theta$ in a certain way: $z=w(y,\theta)$. Control law $W_I(\cdot)$ is determined by the function w(·) reflecting a structure of the passive controlled object and information I, which has agent at time of decisionmaking.

Conditions set Θ is known to all participants TOS and fixed. Decision-making model of control center is generally similar to above mentioned decision-making model of agent and is described by tuple, wherein subscript «0» denotes a variable selected center $\Psi_0 = \{U_A, U_v, U_I, A_0, \Theta, w(\cdot), v_0(\cdot), I_0\}$ [9-10]. Under uniformity of decision making models described in multi-level hierarchical systems control center can be regarded as a subject. It is controlled by a higher-ranking center and agent as a center, which controls lowerranking agent. Control center actions are: $u_A \in U_A$, $u_v \in U_v$, $u_I \in U_I$, $u=(u_A,u_v,u_I) \in U=U_A\times U_v\times U_I$ is a control vector. Indices correspond to the control subjects: index «A» refers to institutional control, «v» - motivational, «I» - informational.

In most models of technical-organizational system it is considered that the only role of control center is to implement the control, i.e. it does not have its own result of the activity. Thus, the result of center is generally considered as a result of agent activities [8-10], which are controlled using modern approaches [11-15]. Since center preferences $v_0(\cdot)$ are defined, including the set of possible outcomes A_0 agent activity, which are depended on agent actions and

conditions, so control center function is to stimulate agent to choose certain actions. In case of uncertainty in the system, it is assumed that unit, using particular rule, eliminates uncertainty and makes decision in full awareness.

Thus, objective of this work is to develop a method of automatized control of ore-preparation and ore-dressing technological processes at the ore-dressing and processing enterprise, whose structural units have their own preferences in relation to technological and organizational processes.

2. Method of coordinated automatized control of a mining and-processing enterprise

Mineral processing of iron ore in Ukraine includes raw ore mining, crushing. milling and magnetic dressing as shown in Fig. 1. All these processes are realized at the mining and processing enterprises (MPE), including a mine, a crushing plant (CP) and an ore-dressing plant (ODP).

The task of the control center is the collection and analysis of mine, CP, ODP production indices and development a coordinated optimal plan of mining and processing of ore types. The most important unit of mining and processing enterprises is an oredressing plant, products of which determine efficiency of the entire plant.

Consider the automatized control process of technical-organizational system "control center – ore-dressing plant". In general, agent objective function is described as the difference between amount of stimulation proceeds and production charges $f(y)=\sigma(y)-c(y)$, and center - the difference between sale proceeds and stimulating charges $\Phi(y)=H(y)-\sigma(y)$ [9]. All components of the objective functions should be expressed to single monetary value.

It should be noted, that most of mining and processing enterprises process several technological ore types [3]. Quantity and quality of concentrate from various ore types differ with their characteristics: ρ_j - iron content in the j-th ore type; η_j - extraction of iron from the j-th ore type; σ_j - extraction of concentrate from the j-th ore type; w_j - specific energy cost per ton of processed j-th ore type ($j=1,\ldots,N_r$), N_r - the number of ore processed ore types.

Action of ore-dressing plant as an agent is performance of control center task for production of given concentrate volume y. To fulfill the task

an ore-dressing plant must process $\overline{m}$ tone of N_r ore types, which depends on the task of control center and the technological characteristics of ore types

$$m_j = \frac{y_j}{\sigma_y}, \quad j=\overline{1,N}, \qquad (1)$$

where y_j is the mass of concentrate, produced by processing of the *j*-th ore type; σ_j is the concentrate extraction from the *j*-th ore type; N_r is the number of ore types.

Rational behavior of considered technicalorganizational system participant is to minimize their own costs in terms of all available information about technological and organizational processes. According to the characteristics of each ore type objective function of agent – ore-dressing plant is as follows

$$c(y)=\sum_{j=1}^{N_r}\left[\frac{y_j}{\sigma_j}w_j\,C_e\right]\to\min,\ j=\overline{1,N_r}\quad(2)$$

where w_j is the specific energy consumption for processing one ton of *j*-th ore type; C_e is the price per 1 kW•h of electricity.

Objective function of control center is the sale proceeds of concentrate

$$H(y)=C_c\sum_{j=1}^{N_r}y_j\to\max,\quad(3)$$

where C_c is the contract price per ton of finished ore (concentrate).

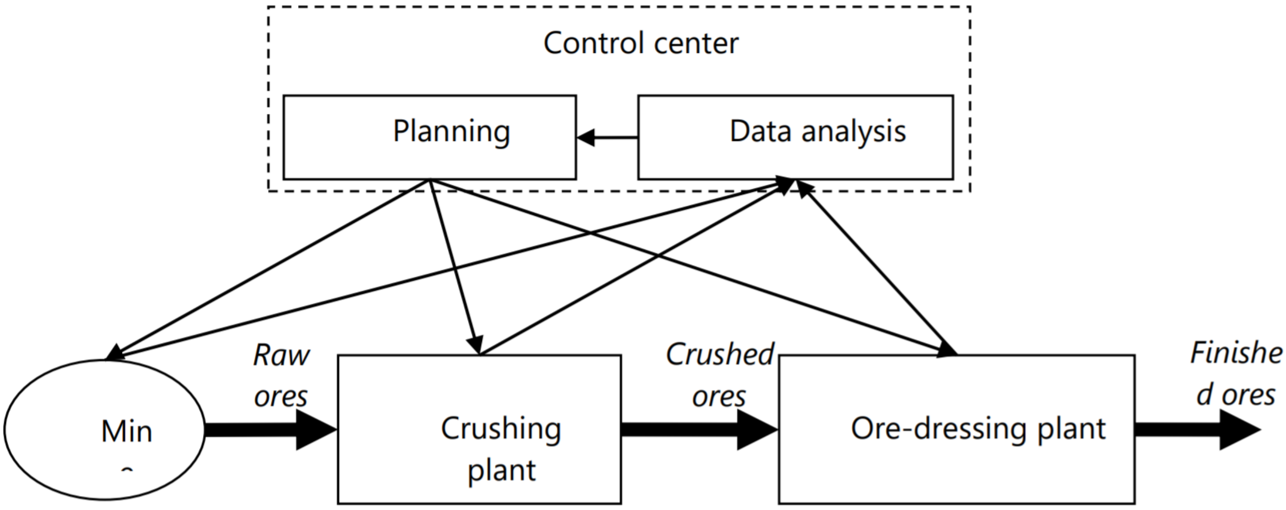

Figure 1. Typical structure of mining and processing enterprise

Furthermore, the production plan should comply with the contractual obligations of the ore processing enterprise to produce and supply a certain mass of concentrate given quality

$$y^{(l)}\le y\le y^{(h)},\ \alpha^{(l)}\le\alpha(y),\ i=\overline{1,N},\quad(4)$$

where $Y^{(l)}$, $Y^{(h)}$ is respectively the minimum and maximum allowable value of concentrate volume; $\alpha^{(l)}$, $\alpha^{(h)}$ is respectively the minimum and maximum allowable value of iron content in the concentrate.

The iron content in the concentrate produced from several types of ore is described by the dependence

$$\alpha(\overline{m})=\frac{\sum_{j=1}^{N_r}m_j\rho_j\eta_j}{\sum_{j=1}^{N_r}m_j\sigma_j}=\frac{\sum_{j=1}^{N_r}\frac{y_j}{\sigma_j}\rho_j\eta_j}{\sum_{j=1}^{N_r}y_j},\ j=\overline{1,N_r}\quad(5)$$

where ρ_j – iron content in the j-th ore type; η_j – extraction of iron from the j-th ore type.

It should be noted, that the accessible volume of each type for each production line of ore-dressing plant for the t period is limited

$$0<m_j(t)\le m_j^{(h)}(t),\quad j=\overline{1,N_r}\quad(6)$$

where $m^{(h)}_j$ is the mass of j-th ore type reserve.

Thus, the control center should select a system of stimulation σ(y) to encourage an oredressing plant to fulfill given production plan y. Knowing that the ODP chooses the action, which maximizes its objective function, control center has to find such a stimulation system, that will maximize its own objective function. Meanwhile, it is considered that hypothesis of benevolence is satisfied. According to the mentioned hypothesis, ODP chooses one of several production plans, which give a global maximum for its objective function being the most favorable for the control center [8-9]. From the control center standpoint stimulation may not exceed the income received by it from ODP activity. From the ODP standpoint stimulation proceeds σ(y) should not be less than production charges c(y) and reserved utility, which can be obtained by choosing a zero ore producing.

The Pareto optimal plan of control center is appropriate to use the recovery of expenses principle for an ore-dressing plant operation [9]. According to the principle, inducing the ODP for choosing action is enough to compensate it for production costs. Besides compensation costs, the center also pays a motivating premium δ≥0. Therefore, in order for an ore-dressing plant to produce a required concentrate volume, the simulation from the center for the choice of this action should be at least

$$\upsilon(y) = c(y) + \delta = \sum_{i=1}^{N_p} \frac{y_j}{\sigma_j} w_j \quad C_e + \delta \qquad (7)$$

Since the stimulation proceeds is equal to ODP production costs, the optimal production plan y^* is the plan, that gives maximum difference between income of the control center and costs of ODP [9]. Consequently, the optimal realizable plan can be found by solving the following optimization problem

$$y^* = \operatorname{argmax}\{H(y)\ c(y)\}. \qquad (8)$$

It should be noted, that the operational planning of mining and ore processing at enterprises is carried out periodically with several intervals. Thus, ODP objective function takes the form

$$c(y,t) = \max_{t=1\approx T} \sum_{j=1}^{N_r} \frac{y_j(t)}{\sigma_j} w_j C_e \to \min, \quad j = \overline{1,N_r}, \qquad (9)$$

$c($where T is the number of intervals in the planning period. The objective function of control center takes the form

$$H(y,t) = \min_{t=1\approx T} C_c \sum_{j=1}^{N_r} y_j(t) \to \max \qquad (10)$$

General optimization model in consideration of (8) takes the form

$$\overline{y^*} = \operatorname{argmax}\left\{ \begin{array}{l} \min\limits_{t=1\approx T}\left\{ C_c \sum\limits_{j=1}^{Nr} y_j(t) \right\} \\ \max\limits_{t=1\approx T}\left\{ \sum\limits_{j=1}^{Nr} \left[\frac{y_j(t)}{\sigma_j} \quad w_j \quad C_e \right] \right\} \end{array} \right. \qquad (11)$$

rections

$$\begin{array}{l} Y^{(l)} \le y(t) \le Y^{(h)}, \quad t = \overline{1,T} \\ \alpha^{(l)} \le \alpha(y,t) \le \alpha^{(h)}, \quad i = \overline{1,N}, t = \overline{1,T} \\ 0 < \sum\limits_{t=1}^{T} \quad m_j(t) \le m_j^{(h)}, \quad j = \overline{1,N_r}. \end{array} \qquad (12)$$

Optimization problem (11) is solved using the Sequential Quadratic Programming (SQP) method.

Table 1. Characteristics of ore types

Characteristic	Types			
	I	II	III	IV
ρ, %	29,1	28,5	30,4	34,0
η, %	79,4	78,1	75,4	75,1
σ, %	34,9	35,1	36,2	38,5

Results. A mining and processing enterprise requires in the plan period t=1,..,T days, making ore dressing of four ore types with the iron rate in concentrate 63,2-64,5%. Every day's concentrate volume is required to be in the range of 1300-1600 tons. Testing the coordinated control method of ore mining and processing enterprise technological and organizational processes for the seven-day period (number of intervals T=7) was specified. The cost for 1 kW•h of the electric power is 0,9733 UAH. The cost for 1 ton of a concentrate is 821,49 UAH. Characteristics of ore types are shown in Tab. 1.

The change in the main indices of the oredressing process is shown in Fig. 2-4. The function of the enterprise's income (Fig. 2) is within the limits of 1-1,2 million UAH. The iron content in the concentrate (Fig. 3) throughout planning is within the set limits of 63,2-64,5%. Thus, the necessary output of a concentrate (Fig. 4) is provided.

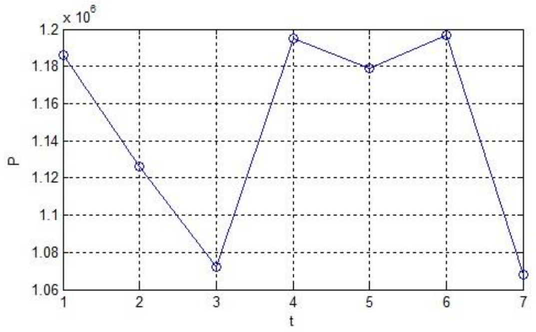

Figure 2. Income of the enterprise

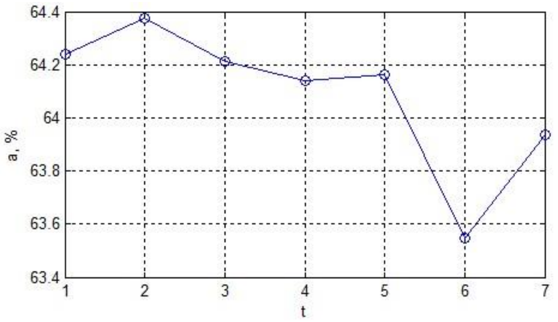

Figure 3. Iron content in concentrate

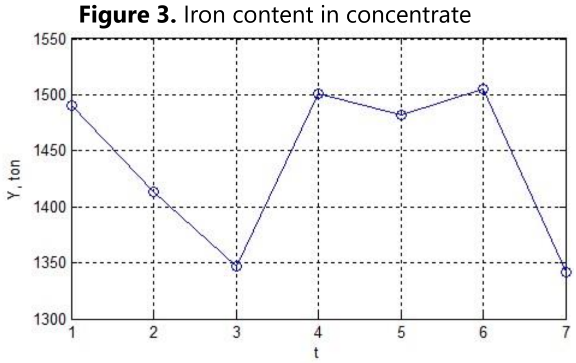

Figure 4. Amount of produced concentrate

Thus, the offered approach of organizational and technical production control at the mining and processing enterprise allows to improve the control quality.

Conclusion. The approach under consideration provides new prospects for increasing quality of automatized control of mining and processing enterprise as a technicalorganizational system in market economy terms taking into account own preferences of each structural unit.

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