

Performance evaluation of functioning of natural-industrial system of mining-processing complex with help of analytical and mathematical models

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Abstract. The article describes research and analysis of hazardous processes occurring in the natural-industrial system and effectiveness assessment of its functioning using mathematical models. Studies of the functioning regularities of the natural and industrial system are becoming increasingly relevant in connection with the formulation of the task of modernizing production and the economy of Russia as a whole. In connection with a significant amount of poorly structured data, it is complicated by regulations for the effective functioning of production processes, social and natural complexes, under which a sustainable development of the natural-industrial system of the mining and processing complex would be ensured. Therefore, the scientific and applied problems, the solution of which allows one to formalize the hidden structural functioning patterns of the natural-industrial system and to make managerial decisions of organizational and technological nature to improve the efficiency of the system, are very relevant.

1. Introduction

When considering the natural-industrial system of a mining-processing complex, numerous problems arise that require the evaluation of quantitative and qualitative regularities of the processes of its functioning [1-3]. The strategy of sustainable development of the natural-industrial system (NIS) of the mining and processing complex is developed from the position of a system approach that unites technical and economic aspects into a single whole.

The most comprehensive study of the system development is the consideration of the system of indicators, each of which reflects individual aspects of sustainable development (technological, economic-social and technogenic), and the development of an integral criterion, by which it is possible to judge the degree of stability of technological, socio-economic and technogenic development of NIS.



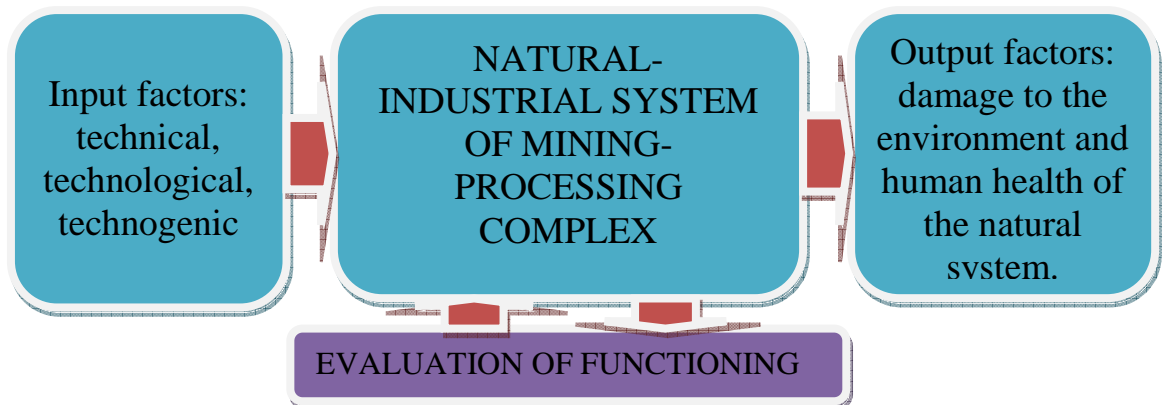


Figure 1. A generalized scheme of the natural-industrial system of the mining and processing complex.

2. Materials and methods

The solution of the problems is based on the system approach that includes instrumental research methods, mathematical modeling, factor analysis, mathematical statistics methods, and application of the full factorial experiment.

3. Analysis of hazardous processes and efficiency.

The task of the analysis is to determine the degree of influence of different parameters and their gradation on the hazard and efficiency of the system functioning. It is especially important for those parameters that are not directly included in the formula for efficiency calculation. The analysis is suggested to be carried out on the basis of calculation of frequency and probabilistic contributions to hazard and efficiency.

Frequency contributions are determined by statistical data:

$$W_{jr} \frac{N_{jr}^b}{N_{ad}},$$

where N_{jr}^b is the number of hazardous states by condition containing gradation r of parameter j ; N_{ad} is the number of all dangerous states:

$$Y_i \leq Y_{ad}.$$

These contributions make it possible to identify those gradations of the influencing parameters, which most often lead to a deviation of the system efficiency below the minimum acceptable level.

Probabilistic contributions are determined by solving the problem of identifying an analytical model from statistical data [1-3]. The logical function is put in correspondence to each state of the system from the statistics. Thus, the transition from the database to the knowledge base is carried out in the form of a system of logical equations:

$$Z_{lr_1^1} \wedge \dots \vee Z_{jr_1^1} \vee \dots \vee Z_{nr_1^1} = y^1$$

$$Z_{lr_1^t} \wedge \dots \vee Z_{jr_1^t} \vee \dots \vee Z_{nr_1^t} = y^t$$

$$Z_{lr_1^T} \wedge \dots \vee Z_{jr_1^T} \vee \dots \vee Z_{nr_1^T} = y^T$$

Variable y takes value 0 for states that satisfy condition: $Y_i \leq Y_{ad}$ and value 1 in the remaining cases. The logical function is brought into an orthogonal form:

$$y_f = z_1 \vee z_2 \bar{z}_1 \vee z_3 \bar{z}_2 \bar{z}_1 \dots,$$

The function allows one to substitute corresponding event probabilities instead of the logical variables and multiplication and addition instead of the conjunction and disjunction signs. Thus, from the system of logical equations, one can proceed to the system of probability polynomials:

$$\begin{aligned} &v_{1r_1^1} + v_{2r_2^1}(1 - v_{1r_1^1}) + v_{3r_3^1}(1 - v_{1r_1^1})(1 - v_{2r_2^1}) + \dots = P^1 \\ &\dots\dots\dots \\ &v_{1r_1^t} + v_{2r_2^t}(1 - v_{1r_1^t}) + v_{3r_3^t}(1 - v_{1r_1^t})(1 - v_{2r_2^t}) + \dots = P^t \\ &\dots\dots\dots \\ &v_{1r_1^T} + v_{2r_2^T}(1 - v_{1r_1^T}) + v_{3r_3^T}(1 - v_{1r_1^T})(1 - v_{2r_2^T}) + \dots = P^T \end{aligned}$$

Here v_{jr} is the probability at which the gradation of the parameter causes an undesired event (the efficiency is below the allowable one); r is the gradation number; j is the parameter number. These probabilities are contributions that are determined by the solution of the identification problem [1-3].

The total number of states of the system is large. Only a part of them is realized in statistics. The results of the probabilistic analysis allow us to assess the risk of fact that the efficiency will be below the minimum allowable value for the net unrealized states of the natural-industrial system. To do this, it is necessary to substitute probabilities v_{jr} that are corresponding to the gradations of the influencing parameters.

In addition to gradation contributions, it is possible to determine the contributions of parameters in general, reflecting the degree of their influence on the risk of an undesirable event:

$$v_j = \sum_{r=1}^{N_j} v_{jr} \cdot p_{jr}$$

where N_j is number of parameter gradations j ; p_{jr} is frequency of appearance of gradation r of parameter j in statistical data.

4. Development of analytical efficiency models.

Efficiency models. When calculating the probability of system states, it is not always possible to neglect the dependence of the influencing parameters. In this connection, three models are considered [4-5].

The model without dependence. Since the interrelation of the parameters among themselves is not taken into account, probabilities can be substituted instead of the corresponding logical variables. Let us obtain the following formula for calculating the probability of state i :

$$p_i = P(y_i) = p_{1r_1} \dots p_{jr_j} \dots p_{nr_n}$$

Here it is possible to calculate the probability of any of the possible states of the system, and thus, to restore information about states that are not found in statistics.

The model with full account of the dependence between the influencing parameters uses a multidimensional joint distribution [4]. In this case, the probability of state i of the system is:

$$P_{1r_1-2r_2-\dots-nr_n} = \frac{N_{1r_1-2r_2-\dots-nr_n}}{N},$$

where $N_{1r_1-2r_2-\dots-nr_n}$ is number of combinations of states $1r_1 - 2r_2 - \dots - nr_n$.

When using this model, only parts of the states will be different from 0. All others are considered impossible. The joint distribution contains all the information about the relationship between the

influencing parameters. This is its dignity. The disadvantage is that it provides information only about the states that have been encountered in history. In order for the distribution of the efficiency parameter to be reliable, it is necessary to accumulate information for a sufficiently long period of time.

The model taking into account the dependence of the influencing parameters on the external factor has the following assumption: the parameters influencing the system efficiency do not depend on each other, but depend on some external parameter. Let us call it an external factor. This approach is of interest mainly in solving problems related to investments. As an external factor, one can take the index of the stock market [6-8].

The function describes all states of the system. Let us write down the function for state i , taking into account the influence of factor f :

$$y_i = \left[\left(z_{1r_1} \wedge \dots \wedge z_{jr_j} \wedge \dots \wedge z_{nr_n} \right) | f = f_1 \right] \vee \dots \\ \left[\left(z_{1r_1} \wedge \dots \wedge z_{jr_j} \wedge \dots \wedge z_{nr_n} \right) | f = f_k \right] \vee \dots \\ \left[\left(z_{1r_1} \wedge \dots \wedge z_{jr_j} \wedge \dots \wedge z_{nr_n} \right) | f = f_K \right]$$

where $r_1 \in \{1, N_1\}$, $r_j \in \{1, N_j\}$, $r_n \in \{1, N_n\}$, $k \in \{1, K\}$.

Each of the states of the system is composite. Its parts are distinguished by different gradations of factor f : f_1, f_2, \dots, f_{N_f} . All terms are orthogonal to each other since the states of the factor are orthogonal since they constitute the GNS. Let us write the probability formula for state i :

$$p_i = \left(p_{1r_1|f_1} \dots p_{jr_j|f_1} \dots p_{nr_n|f_1} \right) \cdot p_{f_1} + \dots \\ p_i = \left(p_{1r_1|f_k} \dots p_{jr_j|f_k} \dots p_{nr_n|f_k} \right) \cdot p_{f_k} + \dots \\ p_i = \left(p_{1r_1|f_K} \dots p_{jr_j|f_K} \dots p_{nr_n|f_K} \right) \cdot p_{f_K}.$$

Probability $p_{jr_j|f_k}$ is the frequency of appearance in the statistics of gradation z_{jr} parameter j , provided that factor f has gradation f_k :

$$p_{jr_j|f_k} = P(z_j = z_{jr} | f = f_k).$$

As in the case without dependence, the logical function helps to restore states that are not met in statistics. At the same time, due to the consideration of the dependence, it is possible to increase the accuracy of forecasting the model.

5. Conclusion

An alternative to the technogenic development of natural-industrial complexes is their sustainable development, which provides an increase in the technical and economic efficiency of production due to the acceleration of scientific and technological progress, the growth of the social standard of the population living, the provision of present and future generations of people with natural resources and favorable conditions of the natural environment.

The technogenic type of technical and economic development can be characterized as a nature-destructive type of development without taking into account technogenic constraints. Characteristic features of technogenic development are: rapid and exhausting use of non-renewable natural resources, especially minerals; overexploitation of renewable resources at a rate exceeding the

possibilities of their natural restoration and reproduction; the volume of contamination and waste exceeding the standards.

Investigations of the mining and processing complex with the help of the considered models make it possible to evaluate the functioning efficiency of the natural-industrial system and make decisions on the prevention of hazardous processes.

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