MINING

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FORMATION OF THE MODELS OF MINING ENTERPRISE MANAGEMENT

Purpose. To develop a comprehensive model of a mining enterprise, to define types of models for mathematical modelling at all management levels, and to determine principles and approaches to the formation of new input data concerning both technologies and their subsystems while combining the technologies.

Methodology. To achieve the goal, a systems approach is used, which allows selecting the types of models for modelling the enterprise activities in terms of technologies and subsystems and determining the method of generating own input data for them. For this purpose, the following was completed: the available literature and patent sources were processed and generalized; scientific and technical papers on the selection and application of the varieties of models in mining were analyzed; the principles and individual approaches to the input data formation for mathematical modelling were considered. That makes it possible to select a software mechanism and create simulation models for effective management of a mining enterprise.

Findings. Types of models for mathematical modelling at the operational, tactical, and strategic levels of enterprise management were determined and substantiated. Connection between the types of models used by management levels was specified. An expert survey for modelling at the operational level, simulation modelling at the tactical level, and dynamic programming at the strategic level of management were selected. A schematic diagram of modelling of a mining enterprise, whose structure included technologies and their subsystems at various management levels, were developed. The principles of input data formation to model all subsystems, either operating or being prepared for their implementation, were studied. The authors' own approaches to the input data formation at the levels of management and technological subsystems were defined.

Originality. While performing a particular solution of the discrete problem by Bellman method, dependences of minimizing the operations for enterprise management while forming a technological chain of a mine, provided meeting the requirements of production process continuity, were obtained. These studies are aimed at establishing a complex information system with its division into elements, each of which is then used to simulate the whole mining enterprise.

Practical value. It means developing a comprehensive model of a mining enterprise, determining the types of models for mathematical modelling at all management levels, establishing a new way of input data formation in terms of both technologies and their subsystems with the implementation of additional mineral-mining technologies.

Keywords: *enterprise subsystems, management level, simulation of reality, dynamic programming, mining enterprise model*

Introduction. Modern technological progress and considerably branched industrial processes require both long-term and short-term predictions of their operations. That leads to the development of new modelling methods along with adaptation of the available ones. As a result, on the one hand, modelling capacities are experiencing their expansion; on the other hand, selection of the models is being complicated. Along with that, modelling capacities are being constantly intensified by modern powerful means of computer-base computations and software products. It is a well-known fact that selection of a model is one of the fundamental tasks of scientific inquiry.

Another aspect of modelling is represented by the input information that influences greatly both modelling quality and its behaviour while modelling. Moreover, heightened attention should be paid to the input data formation to model operations of a mining enterprise, where some other mineral mining technology is functioning or being prepared to be implemented, as it is a new step in mineral mining. Numerous researchers face a problem of substantiation of the input data set formation for their own mathematical modelling; they usually solve this problem at sole discretion.

It is quite clear that the efficient operation of any mining enterprise requires approved project-accounting, geological-surveying, industrial-technical, sanitary-hygienic, and accounting-auditing documentation as well as a situational surface plan with all represented objects and buildings within the mining allotment [1]. All the materials should be provided by the engineering and technical service of a company according to the generally accepted normative instructions; these documents should contain the field-specific unified terminology [2].

The analysis of all technical documentation of mining enterprises carried out in the abovementioned paper has made it possible to classify it according to the operation types:

- geological documentation – mode of mineral occurrence, characteristics of enclosing rocks, types of geological disturbances, plans of mining operations;

- surveying documentation – location of mine workings as for mineral occurrence, plans of mining operations;

- description of stoping operations – technology of stoping operations, calculation of their parameters;

- descriptions of preparatory operations – technology of preparatory operations, calculations of their parameters;

- auxiliary mining and technical documentation: transportation scheme and calculation of freight flows, schemes of the location of electric equipment and electric networks, location of communication means, calculation of air distribution in mine workings, location of fire extinguishing means, plan of emergency response, and others.

The documentation is the output data for the development of simulation models. They mean replacing real mine objects with the modelled ones. Accordingly, managerial decision-making is transferred onto the screen of a dispatcher service or a head of a corresponding structural subdivision. That is the subject to be focused on by the represented study.

Literature review. Numerous researchers dealt and are still dealing with the problem concerning selection of model types to simulate company operations; each specialist chooses his/her own approach to this issue. The papers where individual models for mining enterprises were developed having been considered, it has been identified that there are not many of them, i.e. the model selection is of individual nature lacking proper systematization. Even fewer researchers deal with the problem concerning formation of the models of mining company operations where some other mineral mining technology is functioning or is being prepared to be implemented [3]. The papers by such authors as S. M. Honcharenko, M. S. Surhai, E. I. Rohov and others are devoted to thorough substantiation of the selection of mathematical models. Analysis of this specific field of studies is represented in paper [4].

The input data used in a model is another aspect of the model development, being also rather important. The already mentioned scientists as well as A. V. Sokolovskyi [5] and others were involved in solving this problem while dealing with their own scientific tasks. M. S. Surhai developed an information model of mine functioning and determined its performance. While using his developed technical and economic model of an ore mining enterprise and determining its performance, S. M. Honcharenko managed to make strategic decision concerning the whole company development. A. V. Sokolovskyi defined operating parameters of an open pit and its indices basing on his own information sources; that helped him generalize all company systems to increase its overall efficiency. M. V. Sokolov developed a system of the company's operating results to improve stability of its functioning and specified his own input data basing on the previous experience of company operation.

Modelling is widely used in all engineering disciplines mostly due to the fact that it implements principles of decomposition, abstraction, and hierarchy [6]. Each model describes certain part of a branched system of processes. A new model is developed on the basis of several older ones being morally obsolete or providing no reliable results within the admissible limits. Actually, a process of model development is infinite; it depends only on new achievements in a mathematical mechanism of their description and software development. The efficiency of each model is determined by the obtained results both under standard and nonstandard conditions. Comparison of the modelling results with the field ones helps introduce corresponding software modifications and corrections.

In terms of dissertation studies and a series of publications by R. Dychkovskyi, described in detail in paper [7], modelling is based on a principle of replacing the parameters and processes of mining objects by the modelled elements. In this context, corresponding allowances are provided while representing virtual reality [8]. Use of automation of all production processes is an important component of the development of simulation models [9].

Papers [2, 7, 10] show that the simulation modelling structure is divided into three sectors.

1. Ideal idea means maximum convergence of the results of both a real object and a model. Here, the analyzed processes and objects are represented by means of corresponding transfer coefficients. That allows obtaining the required modelling reliability.

2. Zone of variable data – this segment is changeable. The required convergence is obtained by comparing the results of a model and under real conditions. Only in terms of certain data variations and getting more effective mathematical models, one can obtain the results on a model that will meet the real results in a mine. It is the sector that is the most favourable one for modelling in mining.

3. Disaster zone is a segment where correspondence of the parameters is not kept on the objects of model and reality. However, it does not mean that this modelling segment is not used in mining. Authors of the current paper consider it expedient to use a "disaster zone" for simulating the representation of mining reality that is aimed only at visualization of certain objects not requiring the complete scaled correspondence.

It is no doubt that each scientist should try to increase probability of the modelling results using the "ideal idea" sector; nevertheless, formation of the enterprise management models lies in the "variable data" sector.

Unsolved aspects of the problem. The unsolved problem is in the development of a complex model of a mining enterprise at the synthesis of technologies that takes into consideration types of separate constituent parts. The studies mean selection of a mathematical regulation mechanism for the mining enterprise links to make preliminary managerial decisions at all levels of mining production. The studies also involve determination of principles and approaches to the formation of proper input data and obtaining results according to the technologies and their subsystems.

Thus, the research object will be represented by a mining enterprise where two mineral mining technologies are being used in the joint production environment. The research subject will be as follows: technologies of mineral mining within one mining enterprise being either in current operation or prepared to be implemented in the joint production environment.

The authors of the study are going to develop elements of a complex mining enterprise model, select and substantiate the types of components of its elements to form managerial decisions for the following five subsystems: extent of mineral exploration; equipment, technology; economy; and organization.

The purpose of the paper is to study the components of a mining enterprise, form a system for visualization of mining operations, and improve the mine management models including the cases when several mining technologies are combined.

Methods. To form the models, the paper uses a complex approach that involves certain tasks:

- analysis of the cutting-edge national and foreign practice while developing simulation systems for representing production processes at mining enterprises;

- identification of tendencies in the technical and technological improvement of the production processes;

- selection of the methods to consider processes in terms of certain production links;

- development of a system to represent simulation of the mine components;

- formation of a visualization system while managing a company and its components;

- elaboration of the measures for reducing environmental impact on the Ukrainian mining regions;

- identification of the limits of economic expediency to apply the proposed measures.

Each mining enterprise as a separate structural unit dealing with mineral mining has a series of compound situational elements that determine its operating efficiency [11]. Use of more effective mining equipment, changes in technological parameters of a site or qualitative changes in mining technologies result in the necessary reconsideration of all production links as for their compliance with the introduced changes [12].

While forming simulation models, it is important to develop a sequence of elementary actions (modelling algorithm); each of them will be transformed into an understandable computer instruction. In this case, any computational problem can be solved with certain allowances as for the final results. Special programming languages allow transforming specific computational operations into the corresponding programming code [2, 7, 13]. Certainly, while representing virtual reality of certain segments of mining enterprises, high competences of the engineering and technical workers are required as well as powerful system capacities of the applied software. Consequently, there arises the need in outsourcing to attract other programmers. The world practice demonstrates that such companies as "Surpack", "Minex" and others cooperate widely with the mining sector [14].

While modelling, each complicated production system that includes mining enterprises should be divided into certain subsystems. Further, those subsystems are considered separately. In terms of applied information packages, two methods of such division into subsystems are possible: structural (or functional) and objective (component) decomposition [7, 15]. Currently, it is quite difficult for one finite model to combine the whole process of mining company functioning. That is especially true about modelling of complex thermochemical transformations, which are used quite often while mineral mining [16].

Thus, we are not going to develop separate computer programs in this paper; we only want to develop a certain algorithm that will help form such models to complete concrete production tasks. Moreover, a process of simulation representation of the reality should go through the whole mine lifecycle from the beginning of geological prospecting up to the production closure [17]. Considerable attention should be also paid to the already accumulated mining wastes and to the provision of environmental safety of regions [18]. In terms of such an approach, variation of the obtaining of final software product is possible basing on the final economic expediency [19]. At the same time, there are negative tendencies peculiar for a coal mining complex, which should be taken into consideration anyway. They are as follows: depreciation of main production funds, increasing capital expenditures for production, growing costs for mineral transportation [20]. In the long term, these tendencies result in the increasing prime cost of mining and reduced labour productivity per worker [21].

Basing on the aforementioned facts, the authors propose to perform conventional division of mining production of a mine into macro- and microlevels while developing simulation models. Next, relying on the ranging of significance of certain factors, the authors offer to represent corresponding allowance basing on the mentioned system "ideal idea – variable data – disaster zone". Then, corresponding mathematical mechanisms are to be selected for each of the sectors to represent virtual reality of the field object. The defined transfer coefficients will make it possible to provide adequacy of the managerial decisions while changing the technological parameters of mining processes and analyzing current changes in the whole cycle of company functioning.

Formation of the simulation model for mining processes. A mining enterprise is considered as a system where there is certain exchange with material and technical resources between the internal elements and external environment. Its internal elements are grouped according to the technologies and further according to the subsystems providing its functioning. The number of subsystems is similar for all technologies but different in the number of internal indices and input parameters [22]. While thinking what the primary thing for modelling is, we can conclude that selection of a model of input data preparation in terms of subsystems can be carried out at a similar level. It means that first you need to identify the types of mathematical models at the management levels and then prepare the data for subsystems with further modelling; or vice versa, you need to prepare data for the subsystems considering the management level with its further modelling in terms of the selected model types.

Since there is no priority as for tendencies in model development, we propose to start by selecting the types of mathematical models taking into account the management level. To do this, we form a schematic diagram of a general mining enterprise model considering the management levels and technology subsystems (Fig. 1).

The development of computer technology and software systems has resulted in the fact that the models are selected according to the principle of information availability and the programmer's experience as well as their use in the sphere of modelling of various processes at mining enterprises and definite production needs. In our case, the selection and substantiation of the models are to be started from the lower management levels.

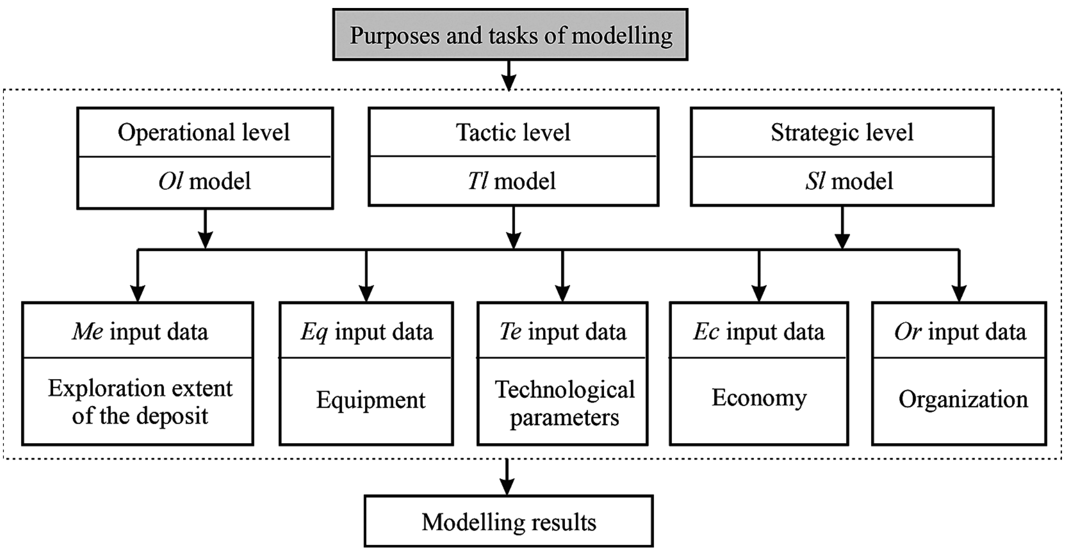

Fig. 1. Schematic diagram of a general mining enterprise model taking into account management levels and technology subsystems

Thus, consider the models for the operational level that covers decisions at a lower production level in the short term. It is hard to formalize and describe with equations a considerable number of such models. Hence, it is required to find the model type that will provide a sufficient level of decision-making certainty. Moreover, a great number of issues at the operational level depend on the workers' decisions on the spot. One of the models that can provide it properly is expert survey where questioning helps obtain ready decisions for both standard and nonstandard cases from the focused specialists without the necessity of problem formalization. It is more than enough to adopt that modelling method at this level.

Consider the detailed formation of a model for expert survey where key element is represented by specialists (experts), who form the modelling purposes, a set of input conditions, and the questions to be asked. Define the algorithm of model development with the help of expert survey for a mining enterprise (Fig. 2):

1) formation of the modelling purpose with the problem description, the available statistic data, reference materials etc. are defined;

2) preparation of the information materials where experts should consider the problem from the different viewpoints;

3) formation of the issues for survey where experts will specify a concrete set of questions, their significance, and other parameters with the following requirements: questions are focused on one problem; a question should be short; two questions are not allowed to be in one question; question statement should not influence the respondent to answer in the way desired by the researchers; a questionnaire should not contain too many questions; available control and indirect questions;

4) selection of respondents to be questioned; they should have certain experience in the fields the questions are about; while selecting respondents, one should consider personal interest that can influence the survey results;

5) questioning;

6) data collection, their analysis and generalization;

7) formation of the recommendations basing on the analysis and generalization of the results.

Analyse the model selection for the next level of management – the tactic one. At this level, a list of corresponding mining company tasks is considered in the medium term. Similar to the operational level, here there are numerous models to be applied. However, we prefer a simulation model

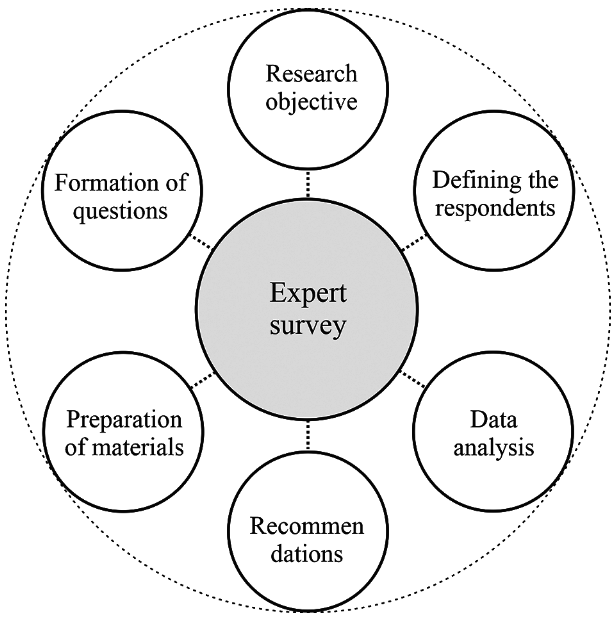

Fig. 2. Model of expert survey for a mining enterprise at the operational level

as it helps represent the object quite accurately with the preserved logical structure and behaviour of the whole system. In terms of such modelling, a structure is modelled quite well and represented adequately by the model; it describes dynamics of mining operations and allows their analysing. In addition, simulation modelling is applied while creating models of discrete or discrete-continuous systems. Such systems are poorly described analytically, and their experimental study is complicated. Besides, the model is created while developing an algorithm that can represent operation of the object being modelled in the accelerated time. That allows applying such modelling to analyse the work of subsystems: exploration extent of the deposit, available equipment, technology, economy, and organization (Fig. 3).

Such a model can be and will be used in the system of calculations aimed at rationalization of tactic decision-making as for regulation of mineral extraction and its material-technical provision in terms of hierarchical management system. For instance, there can be the following objective of a simulation experiment: evaluation of the strategies to control handling of mobile resources, determination of critical (from the viewpoint of costs) traffic of mining operations at levels, identification of the effects of mining conditions, determination and comparison of the costs at different variants of mining schedules, prediction of possible operation sequence per time interval between the successive decisions and others.

As it has been already mentioned, synthesis of the technologies means certain combination of different mining technologies within one enterprise. Then, the trends in the simulation model use involve certain modification of its structure. Consequently, the experiment capabilities are widened at the expense of searching the parameters from a specific value range in terms of the required number of technologies.

Basing on the long-term predictions, for which a simulation model is developed, we will use the variables: exogenous, endogenous, controlled, and generated. While model developing, we can use the variable parameters and allowances based on the hypothesis of mining company functioning. The model elements are represented by mineral deposits, equipment complex, economic indices etc.

The following management level is the strategic one; it is difficult to identify a model type for this level as modelling should cover the long-term period of enterprise operation along with the consideration of technologies, corresponding time of their implementation and company closure and so on. Such tasks are also quite difficult to formalize as a number of probabilistic parameters appear in calculations that complicates significantly the prognosis of company development. Models from the dynamic programming group are rather suitable for such tasks. At this programming, different ways of company progress are modelled and their probable branching is considered as well.

That allows obtaining optimal algorithm of determining the way of company progress from one stage to another where the main principle is the division of a more complex and greater task into the smaller subtasks containing fewer variables. One more very important principle of dynamic programming is that problem solving starts by the last link where the finite state of system development is obtained. That is appropriate for a strategic level of mining company management since we know in advance the amount of deposited mineral and when it will be depleted. If we generalize this approach, we can show a dynamic model in the form of arrow movement that symbolizes optimal decision-making in a great number of decision variants (Fig. 4).

This model is described by the following system of equations where the initial stage deals with solving a discrete problem of operation minimization in terms of meeting the requirements for continuous mining company operation determined as the reversed Bellman method [23]

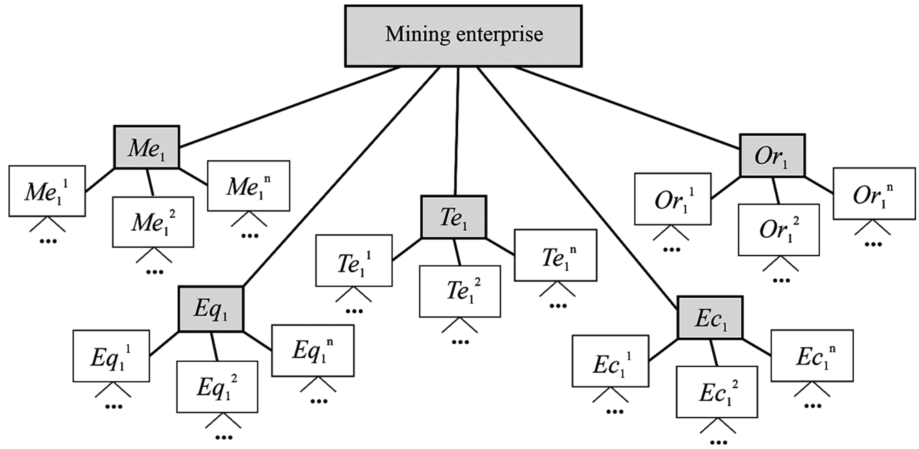

Fig. 3. Simulation model of a mining enterprise at the tactic level:

Me – subsystem "Exploration extent of the deposit"; Eq – subsystem "Equipment"; Te – subsystem "Technology"; Ec – subsystem "Economy"; Or – subsystem "Organization"

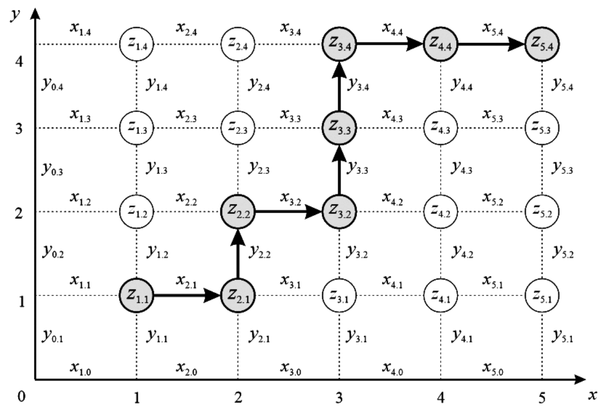

Fig. 4. Scheme of a dynamic model where arrows in bold indicate the optimal decision-making route in the analyzed system at the strategic level

$$x'(y) = f(y, x(y), u(y)); \quad u(y) \in U;$$

$$x(y) = x_0; \quad x(y_f) = x_f; \quad J = J(F(x(y))) \to \min,$$

where x_0 and y_f are vectors of the initial and finite system position in the space of states, respectively; $u(y)$ is a vector of its control; $x(y)$ is a vector of state determining the trajectory in the space of states; $F(x(y))$ is a vector of the optimality criteria.

Relying on the fact that the majority of control objects at the considered stages of a technological process can be approximated as the second-order objects, the system can be reduced as follows

$$x_1' = x_2; \quad x_2' = \frac{x_0}{Y_0} - \frac{x_1}{Y_0} - \frac{Y_1}{Y_0} \cdot x_2,$$

whose boundary conditions are $y_0 = 0$, $x(y_0) = x_0$, $x(y_f) = x_f$, where y_f is time, during which the parameter experiences its decrease; x_f is requirements for the finite parameter. As for the purpose, the requirements can be formulated in the form of restrictions for the components of a state vector. Since the output equation in a general case was the second-order equation, the state vector would have the second order: $x_1 = x$, $x_2 = 1$, where x is the content of the i^{th} class of a problem. In a general case, a problem of optimal control for the selected processes is characterized by the criteria vector $F(x(y))$. As the parameters of system operation are determined by maximization of the optimal working parameters, meaning equipment productivity $Q \to \max$, this criterion is rather widespread.

Having found our position with the model types, we move on to the formation of corresponding input data for each of them. To study the principles of obtaining the input information for mathematical modelling, one can single out their three types. The first one includes quantitative data that can be received from different reports and similar data sources. The second type involves quantitative-qualitative data characterizing partially the quality and quantity of processes (data concerning mining technologies; type and structure of stoping equipment and mining facilities). The third one includes quantitative data on the quantitative characteristic of units and technologies (schemes of mine field opening; methods for deposit preparation; directions of deposit mining) considering the fact that all data can contain accurate information and have values with certain range of variations. Some of them can be obtained by transforming others. That helps reduce the necessary nomenclature of the company performance, having provided more qualitative evaluation of calculation values and formed a comprehensive information model from the system of basic and computational indices of the company activities.

Thus, there are following principles for obtaining the input data for expert, simulation, and dynamic programming [8]:

1) the expert one, performed by questioning a certain group of experts as for the state of company development according to the subsystems;

2) analysis of technical and economic indices of company performance;

3) generation of the data of company operations basing on statistic indices, which allows obtaining the required data.

After that, it is clear that collection of the required input data for modelling will involve a complex of the indicated principles where the company data will be formed separately for each system:

- determining the external factors reduced to actual product value on the internal and external markets;
- data on the deposit exploration representing actual costs for exploration, exploration extent, calculation data of the mineral availability within the mine field and their expert estimation;
- data on the basic types of machines and equipment operating at an enterprise with the determined technical-operating and performance characteristics;
- data on the technological performance of an enterprise characterized by the mining technology and determined from the technical characteristics of their operation;
- data on the company economy where economic indices of an enterprise, obtained by means of statistic analysis and expert reports, are considered;
- data on the company organization including an organizational component of the operations aimed at production preparation, implementation of technologies including the

additional ones, mutual influence and servicing for the technologies.

As a result of the input data set formation, qualitative and quantitative data types are obtained at the operational, tactic, and strategic levels of management.

Conclusions. The paper has identified and substantiated the model types for mathematical modelling at the operational, tactic, and strategic levels of company management. That has made it possible to determine relations between the types of models used in terms of management levels. Basing on the comprehensive data processing, an expert survey has been selected for modelling at the operational level of management; simulation modelling – at the tactic level; and dynamic programming – at the strategic level.

A schematic diagram of modelling of the mining enterprise system has been developed; the diagram includes technologies and their subsystems at different levels of company management. The proposed principle of differentiation of production processes at mines according to the technologies and their corresponding subsystems, which are either operating or being prepared for their implementation, was used to determine our own approach to the input data formation for mathematical models. That information helped make the following conclusions as for development of simulation models of a mining enterprise:

- simulation representation of mining conditions helps simplify considerably a system of managing both the whole company and its components;
- it is necessary to provide correspondence in the system "object-model – object-reality" for each modelling sector (ideal model; variable data; disaster zone);
- the conducted studies are not aimed at developing some separate software product but develop the corresponding algorithmic and virtual code that can be used in the available information packages;
- principles of the input data formation for modelling should be implemented according to the management levels and subsystems of all technologies either operating or being prepared for their implementation.

The research results can be used for developing the concrete mathematical models of the mining company operation at the corresponding management levels.

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Формування моделей управління гірничим підприємством

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Мета. Полягає в розробці комплексної моделі гірничого підприємства, визначенні типів моделей для математичного моделювання на всіх рівнях управління, визначенні принципів і підходів до формування нових вхідних даних за технологіями та їх підсистемами при синтезі технологій.

Методика. Для досягнення мети використано системний підхід, що дозволяє обрати типи моделей для моделювання роботи підприємства за технологіями та їх підсистемами й визначити спосіб формування власних вхідних даних для них. Для цього здійснена обробка та узагальнення літературних і патентних джерел, аналіз науково-технічних робіт із питань вибору й застосування різновидів моделей у видобувній галузі, розглянуті принципи та індивідуальні підходи до формування вхідних даних для математичного моделювання. Це дає можливість обрати програмний механізм і створити симуляційні моделі для ефективного управляння гірничим підприємством.

Результати. Визначені та обґрунтовані типи моделей для математичного моделювання на оперативному, тактичному та стратегічному рівнях управління підприємством. Визначено зв'язок між типами моделей, що використовуються за рівнями управління. Обране експертне опитування для моделювання на оперативному рівні, імітаційне моделювання на тактичному рівні й динамічне програмування на стратегічному рівні управління. Розроблена принципова схема моделювання гірничого підприємства, до складу якої входять технології та їх підсистеми на різних рівнях управління. Розглянуті принципи формування вхідних даних для моделювання усіх підсистем технологій, що працюють або готуються до впровадження. Визначені власні підходи до формування вхідних даних за рівнями управління й підсистемами технологій.

Наукова новизна. Виконуючи окреме вирішення дискретної задачі за методом Беллмана, отримані залежності мінімізації робіт з управління підприємством при формуванні технологічного ланцюга шахти за умови дотримання вимог неперервності виробничих процесів. Дані дослідження направлені на встановлення складної інформаційної системи з розбиванням її на елементи, кожен з яких у подальшому використовується для імітаційного відтворення гірничого підприємства у цілому.

Практична значимість. Полягає в розробці комплексної моделі гірничого підприємства, визначенні типів моделей для математичного моделювання на всіх рівнях управління, встановленні нового способу формування вхідних даних за технологіями та їх підсистемами при впровадженні додаткової технології виймання корисних копалин.

Ключові слова: *підсистеми підприємства, рівень управління, імітаційне відтворення, динамічне програмування, модель гірничого підприємства*

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