Dominant Determinants of Adaptation of the Mining Complex in the Conditions of a Dynamic Environment

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Abstract

Modern business conditions increasingly clearly demonstrate the dynamism of the surrounding world. Such changes in economic, technological, social and economic factors must be taken into account when planning and designing mining operations. In this article, it is proposed to consider the mining region as an anthropotechnical complex from the standpoint of a systemic approach. Management strategy of an open-pit group was developed and nomograms for practical use are given on its basis. Based on this decomposition approach, an adaptation mechanism is proposed. Its principle is that a set of adaptation tools is adopted for each rank of the anthropotechnical complex. The experience of using these tools in the conditions of the Kryvyi Rih mining region is given, in particular, the use of worked out space for the placement of overburden from other open-pits, the joint placement of enrichment tailings and waste rocks, etc. An approach to distinguishing stages and indicators of adaptation according to the proposed mechanism is proposed.

Keywords: *open-pit mining, adaptation mechanism, anthropotechnical complex, adaptation tools, dynamic environment*

INTRODUCTION

The dynamics of fluctuations in demand and prices for products of mining enterprises is characterized by high volatility. At the same time, significant inertia is inherent in the dynamics of fluctuations in the volume of consumption of mineral products, but almost never the graphs of the curves of these dependent indicators are consistent over time.

In economic theory, many thorough studies have been carried out, which particularly interested us, regarding price forecasting by distinguishing cycles of different durations: over a century, over several decades, normal economic cycles, small cycles, specific fluctuations within certain branches of the economy (for example, mining production), etc. Cycles of different durations were named after the names of their researchers: cycles with a duration of 45–60 years (long or large) are Kondratiev cycles; 15–20 are Kuznets cycles; 7–12 (average cycles) are Juglyar cycles; 3–4 years (short or small) are Kitchin cycles [1–2].

The graphs of the dynamics of the price of iron ore from 1980 to 2022 (Figure 1) [3] and world steel production (Figure 2) [4] can serve as confirmation of the above. The second graph is characterized by a constant growth for almost its entire history, while the price at Figure 1 fell by more than 60%.

A number of scientific studies were conducted for conditions of unpredictable price and demand for products of mining enterprises [5–7].

These studies fully explained the effect of the pricing mechanism, established the main interdependencies of cause and effect factors and clearly proved their corresponding regularities. But, at the same time, existing theories do not always allow comprehensively specifying the parameters of a particular manufacturing system, predicting its development, and reliably explaining some inconsistencies that experts constantly encounter, especially in mining [8–10].

This clearly leads to the conclusion about the presence of non-market factors in price formation, which makes it even more difficult to forecast the price of mineral products, without which it becomes impossible to effectively manage the mining complex, which, in fact, determined the direction of the research described below.

The essence of the considered problem is determined by the fact that large mining enterprises are extremely inert manufacturing systems, mostly unable to adequately and promptly change their productivity in accordance with the dynamics of real conjunctural evolutions of the raw material market. Therefore, having practically no levers of influence on this market, they have adaptive capabilities, environment and methods limited exclusively to the internal operational space, the implementation of which becomes possible mainly in the form of clearly targeted and comprehensively dosed adaptive variation of the parameters of the elements of their manufacturing systems.

FORMATION OF A DYNAMIC BUSINESS ENVIRONMENT

Under these conditions, controlling influences on the mining complex, according to the observations of the authors of this study, often lead to quite diverse reactions, both in time and in the network structures of production subsystems, including sometimes quite indirectly connected with the "main

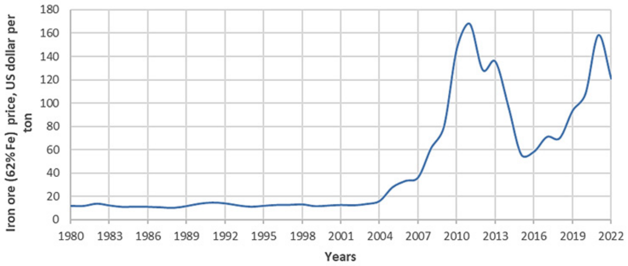

Fig. 1. Iron Ore (Fe 62%) spot price dynamic from 1980 to 2022
Rys. 1. Dynamika ceny spotowej rudy żelaza (Fe 62%) w latach 1980–2022

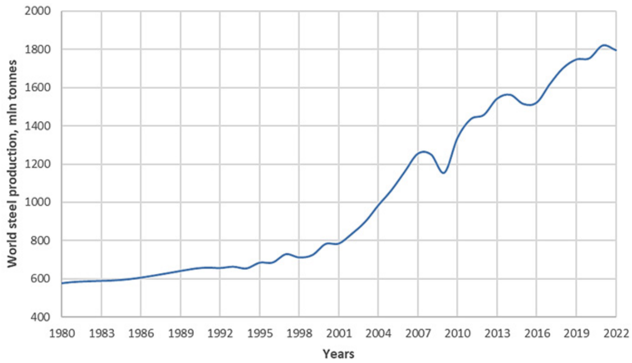

Fig. 2. World steel production from 1980 to 2022
Rys. 2. Światowa produkcja stali w latach 1980–2022

production chain". Not only that, the authors have repeatedly observed a rather unexpected new phenomenon, which by its nature of repetition with fading intensity is remotely reminiscent of the effect of reverberation. We are only developing the study of this phenomenon, as it is hypothetically a mediated manifestation of a certain cyclical nature of the permanent functioning of the mining complex under the influence of external factors, primarily of a strategic level, the scale and effects of which do not correspond to the scope of this article, except for a very brief directed only at them causal analysis.

The main indicators of open-pit mining, which we consider below as an example, at the level of strategic design decisions, are: the mining schedule, characterized by overburden ratio; step-by-step productivity of the open-pit for ore and secondary raw materials and perspective contours of the open-pit. Since it is they who determine the composition and structure of technological complexes (types and quantity of mining equipment with its distribution and grouping), the volume of mining capital works and the construction of industrial facilities, the number of workers, etc. That is, they determine the volume, structure and dynamics of investments, capital and operating costs, and income from the sale of goods. And here, in the conditions of modern post-Soviet Ukraine, two fundamentally opposite problems collide:

1. The total inertia of mining complexes due to the colossal scale and duration of development, as well as the size and productivity of mining machines, which are often unique.

2. Exceptionally dynamic evolution of the global and regional raw material markets as a result of rapid changes in economic and political situations, and most importantly – fundamental transformations in technique and technology caused by the transition of society to a fundamentally new system.

In mining, this duality of the problem is not only not compensated promptly, but even on the contrary it is even more intensified and complicated due to the deepening of mining operations. And all this under the condition that the "life cycle" of mining enterprises is 40 years or more on average.

The development of iron ore deposits of Ukraine at the current stage consists in the fact that mining enterprises work with constant production capacity, which, taking into account the above-mentioned inertness of mines, worked almost perfectly under the conditions of a planned socialist economy, but under current conditions they did not absolutely.

This shows that, in general, the existing mining development strategies are based on an outdated principle, when the final state of mining operations is determined as accurately as possible, which must be achieved after a long period of time. Next, it is recorded what needs to be done in order to reach this final state. After that, an action plan is drawn up with a breakdown by time intervals (five-year periods, years and quarters), the implementation of which should ensure the achievement of the final, clearly set goal. With this understanding, the mining development strategy is a classic long-term plan for achieving a specific final goal, namely a long-term mining plan, in which the volume of ore production is fixed in each specific time period and in the final period.

MANAGEMENT STRATEGY OF AN OPEN-PIT GROUP

This approach is based on the fact that all changes in the external environment are considered predictable, and therefore stable, while significant fluctuations in prices and demand for products are observed in the markets of mineral raw materials. It is almost impossible to predict these fluctuations in the long term due to the above-mentioned problems, therefore, during the operation of open-pits with a constant

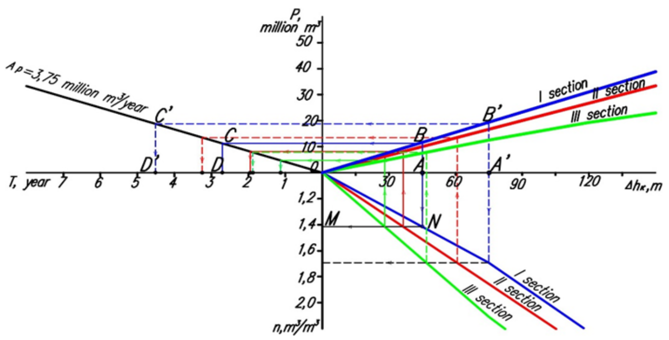

Fig. 3. Nomogram for determining the duration of working out of open-pit sections at different mining intensity
Rys. 3. Nomogram do wyznaczania czasu eksploatacji odkrywek przy różnej intensywności eksploatacji

production capacity, there are additional costs associated with the forced unplanned storage of unsold finished products in the warehouse – during the period of falling demand. And on the other hand, enterprises lose the opportunity to increase profits during the period of growth in demand due to the impossibility of operational intensification of production to cover market needs [11–13]. In this connection, the goals of mining enterprises are changing significantly. The issue of ensuring competitiveness, which depends on the adopted strategy for the development of mining operations, becomes of primary importance. Therefore, this strategy of any combine and Kryvbas as a whole will change.

In the conditions of the market environment, there is a need for adequate adaptation of mining productions to changing market conditions. Examples of such adaptation clearly show that the current mining development strategies (methods of mining development planning and pit design) do not foresee changes in the intensity of deposit development over long periods [14]. At the same time, we note the lack of a mechanism for a reasonable selection of the production capacity of the open-pits and the mining schedule, taking into account their interrelationship when the demand for iron ore raw materials changes. Thus, the increase in demand for minerals, in most cases, leads to an increase in the volume of its extraction, while the strip ratio do not change. A decrease in demand leads to a decrease in the volume of mineral extraction, simple equipment and other fixed assets, a reduction in the number of employees, etc. At the same time, the strip ratios are reduced to reduce the cost of commodity products. The consequence of which is the accumulation of overburden backlog at enterprises, the occurrence of unscheduled temporarily non-working sides at the expense of the violation of the principle of proportional conduct of work and the development of the open-pit space, as well as the formation of temporarily non-working sides in the mining zone, which is unacceptable. Periodically, but inevitably, there is a need to revise previous projects due to the deviation of the actual state of mining operations from the design solutions [15, 16]. Therefore, the mining development strategy should take into account the possibility and mechanisms of adaptive adjustment of the intensity of deposit development when the demand for commodity products changes, both at the level of an individual open-pit or a group of mine pits, and at the level of a group of mines that are part of the same company.

In connection with the above, we have developed a strategy for the development of mining works of open-pits in the conditions of changing demand for iron ore products, according to which this development should ensure the given intensity of working out the deposit, which is determined by the maximum efficiency of the development of the raw material base of the plant in the specified conditions (Fig. 3).

In any case, the volume of production of commodity products of mining and processing plants is adjusted when the need for it changes due to changes in the productivity of open-pits that are part of one plant [17]. Therefore, the optimization of the production capacity of the mining and processing plants that are part of one company can be achieved only under the condition of systematic optimization of the ore productivity of the open-pits that are part of each separate plant. Increasing the production capacity of the plants above the maximum possible values entails the commissioning of new processing factories or the reconstruction of existing ones with more advanced ore processing technology.

The efficiency of the mining and processing plant with different options for productivity and schedule of mining operations in each pit (Fig. 4) can be judged by the economic-mathematical model of the work of a group of pits in the plant system, that shown in Eqs. (1) below:

$$\sum_{t=1}^{T}\sum_{k=1}^{K}\sum_{i=1}^{I}\Bigg(\Bigg(\frac{\sum_{j=1}^{J}(\mathrm{A}_{\mathrm{p\ tkij}}\cdot\gamma_{\mathrm{к\ tkij}}\frac{\beta_{(tkij)}}{\beta_{\mathrm{пл\ (ki)}}}\mathrm{ц}_{\mathrm{tki}})-c_{tki}\cdot\sum_{j=1}^{J}(\mathrm{A}_{\mathrm{p\ tkij}}\cdot\gamma_{\mathrm{к\ tkij}})-BF_{tki}}{(1+E)^t}$$
$$--\frac{\sum_{j=1}^{J}((a_{o\ tkij}+n_{tij}\cdot b_{tij})\cdot\mathrm{A}_{\mathrm{p\ tkij}}+BK_{tkij})}{(1+E)^t}\Bigg)\times(1-N)-$$
$$-\sum_{t=1}^{T}\frac{\sum_{j=1}^{J}\Big(\Big(\Delta V^{y}_{\mathrm{lag(tij)}}+\Delta Q_{\mathrm{гм(tij)}}\Big)k_{\mathrm{in}}+KF_{ti}\Big)}{(1+E)^t}\Bigg)\to max \tag{1}$$

where $\Delta V^{y}_{lag(tij)}$ – increase in annual volumes of overburden lag liquidation at the j-th pit of the i-th plant in the t-th year, m^3
$\Delta Q_{m(tij)}$ – the increase in production capacity of the open-pit by mining mass with an increase in productivity by ore at the j-th pit of the i-th plant in the t-th year, m^3
k_{in} – specific capital costs for increasing open-pit productivity by mining mass, monetary units/m^3;
KF_t – capital investments in the t-th year to increase the productivity of the enrichment factory, monetary units.

ADAPTATION MECHANISM OF THE MINING SYSTEM

Let's take a closer look at the mechanism of adaptation of the mining system to changes in external factors. Managed adaptation of the mining enterprise in this context is a set of

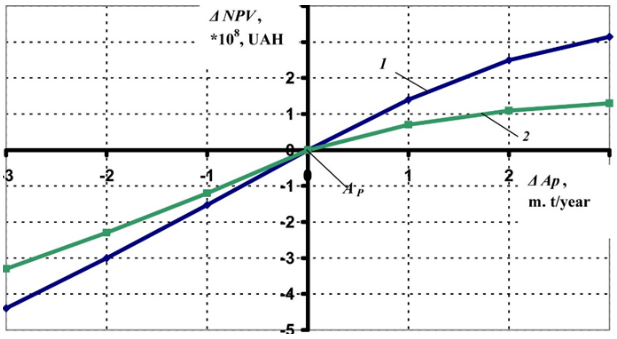

Fig. 4. Change in the annual net present value of cash flows (ΔNPV) depending on the change in productivity (Ap) of ore pits:
1 – Pershotravnevoho; 2 – Hannivskoho

Rys. 4. Zmiana rocznej wartości bieżącej netto przepływów pieniężnych (ΔNPV) w zależności od zmiany produktywności (Ap) wyrobisk rudnych:
1 – Perszotrawnewoho; 2 – Hanniwskoho

organizational, technical and technological measures to preserve or improve the technical and economic performance of the mining enterprise when external factors change [18, 19]. The mechanism of adaptation is a set of phenomena in the environment of its implementation.

To systematize the tools that can be used within the scope of these measures, a decomposition of the mining complex should be carried out from the standpoint of a systemic approach [20].

Mining production can be hierarchically considered as proposed by Prof. Sinchkovsky [21], it is an anthropotechnical system consisting of anthropotechnical complexes of various ranks. The anthropotechnical complex here is understood as a single technical and technological object, which is considered in conjunction with the personnel and ensures the execution of specified production operations.

Mining operations in open-pits are technologically constructed in such a way that each stage of changing the state of the massif or the properties of rocks in the process of their processing requires the functioning of a certain elementary anthropotechnical complex that has its own potential. In the production process, one or another sequence of the use of disparate elements of anthropotechnical complexes in joint work reveals in them the system-forming property of complementing each other, creating a collective potential. Based on this, we can hierarchically distinguish anthropotechnical complexes of three ranks, while the complex of a higher rank includes complexes of a lower rank.

Anthropotechnical complex of the 1st rank is a technological complex of equipment or a complex of mechanization in n open-pit, mine or man-made deposit. For example, an extraction and delivery complex, a drilling and blasting complex, a bulking complex, etc.

Anthropotechnical complex of the 2nd rank is a separate mining enterprise formed by a collection of mining facilities. In other words, it is an extractive production unit that includes anthropotechnical complexes of the 1st rank. For example, an open-pit, a mine, a dump, a separate warehouse, a tailings storage facility, a bulk man-made deposit, etc.

Anthropotechnical complex of the 3rd rank is mining complex. The complex refers to a set of mining enterprises located in the same region and having stable technological, logistical, economic and financial connections between them. Unification of enterprises into such structures becomes possible when mining enterprises belong to the same owner. Then the outlined connections between such enterprises strengthen, and market competition between them, on the contrary, disappears. Accordingly, the market position and technological potential of the entire complex are strengthened. The formation of such complexes begins with the simultaneous development of natural and man-made deposits of individual enterprises, and in the future it is reduced to the management of the schedule of mining operations and the productivity of the entire complex of enterprises.

From the point of view of a systemic approach, at every level the work of a mining enterprise is influenced by external and internal factors. However, depending on the order of the anthropotechnical complex, the same factor can be both internal and external. The change of external factors leads to failure of the rhythmic functioning of the system. However, when managing an anthropotechnical complex of the third rank – a mining complex – the set of internal, controlled factors increases, and therefore the possibilities of system adaptation increase.

Thus, we are talking about the second component of the system adaptation mechanism – adaptation tools. Adaptation tools mean internal factors that can change at the system level of the chosen order. Obviously, the set of these tools will differ for anthropotechnical complexes of each rank.

An example of the implementation of adaptation tools for an anthropotechnical complex of the first rank can be the results of industrial tests at the Petrivskyi quarry of PJSC "Central GZK" of the company "Metinvest" regarding the installation of buckets of increased capacity when working with excavators on overburden. As a result of the difficult economic situation in the country, the company does not have the opportunity to update the fleet of loading and unloading equipment in a timely manner. However, the need to carry out the planned volumes of mining works requires adaptation of the production system. Replacing an 8 m^3 bucket with a 10 m^3 bucket will significantly increase excavator productivity, reduce dump truck loading times and potentially reduce the fleet of primary mining equipment [22, 23].

An example of tools for adapting the second-rank complex can be the implementation of a system for dispatching and automating the operation of the main mining equipment at the open pit of "Inguletskii GZK". The introduction of a single software complex helps to reduce the waiting time of dump trucks for loading by an average of 30–60 seconds. This leads to an increase in the rhythm of the entire quarry, reduces fuel costs and increases the efficiency of equipment use. Since the digitization of production processes by a single system concerns several complexes of the first order, the tool belongs to the complex of the second order.

The management of the developed space [24] within the entire enterprise or adjacent enterprises within the mining complex can be an example of a third-rank adaptation tool [25–27]. For example, for the placement of overburden extracted from the Gleyuvatskiy open-pit of PJSC "Central GZK", the worked-out space of the open-pit №2 of the same enterprise is used, the funnels formed as a result of the underground development of the deposit are filled, and the stop prisms of the tailings storage facility of the plant are formed [28–31].

The next component of the adaptation mechanism of the mining complex is the allocation of adaptation stages:

1) detection of changes in the external environment and assessment of the impact on the system. Depending on the nature of external changes, at this stage the technical-economic, technological and organizational indicators of the system are evaluated in two states: before the occurrence of external changes and after it;

2) selection of a complex rank, at which a decision should be made regarding changes in the internal environment. For this, the components and processes affected by the changes should be studied and determined;

3) calculation and modeling of changes in the internal environment in response to the dynamics of external factors;

4) application of the adaptation tool;

5) evaluation of the result of system adaptation and obtaining conclusions. At this stage, techno-economic, technological and organizational indicators are evaluated after the application of the adaptation tool and compared with the evaluations at the first stage.

A comparison of these indicators allows determining the adaptive potential of the anthropotechnical complex.

CONCLUSION

Thus, the management conditions of mining enterprises are characterized by high dynamics of external factors, and in view of the retrospective analysis, these dynamics will only increase in the future. Mining enterprises in Ukraine partially still offer planned economy approaches in the design of their activities. This problem can be corrected by following the management strategy of the mining complex, taking into account changes in the price of products of enterprises. In their work, mining enterprises must use the mechanism of adaptive management, taking into account the systematic decomposition of mining units.

Future scientific research will be aimed at a more in-depth study of the indicators of the adaptation mechanism of mining enterprises and their adaptive potential.

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Dominujące uwarunkowania adaptacji kompleksu górniczego w warunkach środowiska dynamicznego

Współczesne uwarunkowania biznesowe coraz wyraźniej pokazują dynamikę otaczającego świata. Takie zmiany czynników ekonomicznych, technologicznych, społecznych i ekonomicznych muszą być brane pod uwagę przy planowaniu i projektowaniu działalności górniczej. W artykule proponuje się potraktowanie rejonu górniczego jako kompleksu antropotechnicznego z punktu widzenia podejścia systemowego. Opracowano strategię zarządzania kopalnią odkrywkową i na jej podstawie podano nomogramy do praktycznego wykorzystania. Na tej podstawie zaproponowano mechanizm adaptacyjny. Jego zasadą jest przyjmowanie zestawu narzędzi adaptacyjnych dla każdej rangi zespołu antropotechnicznego. Podano doświadczenia w stosowaniu tych narzędzi w warunkach górniczych Krzywego Rogu, w szczególności wykorzystanie zagospodarowanej przestrzeni do składowania nadkładu z innych odkrywek, wspólnego składowania odpadów poflotacyjnych i skał płonnych itp. Zaproponowano podejście do wyodrębnienia etapów i wskaźników adaptacji według proponowanego mechanizmu.

Słowa kluczowe: *górnictwo odkrywkowe, mechanizm adaptacyjny, kompleks antropotechniczny, narzędzia adaptacyjne, środowisko dynamiczne*