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SYSTEMATIZATION OF ADAPTATION TOOLS FOR MINING ENTERPRISES TO CHANGES IN THE ECONOMIC ENVIRONMENT

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Abstract. The dynamics of demand and price fluctuations for mining enterprise products is marked by high volatility. At the same time, the dynamics of fluctuations in the volume of consumption of mineral products and their prices are characterized by significant inertia, but almost never the graphs of the curves of these dependent indicators are consistent over time. Due to traditional inertia, mining enterprises often lag in adjusting production systems to external economic conditions. Adaptation of mining operations in open-pits to these changes is critically important for ensuring stability and competitiveness of enterprises in dynamic conditions.

The paper analyzes the experience of mining enterprises in adapting to changes in uncontrollable factors and reveals a mostly unsystematic approach to the implementation of adaptation mechanisms. This study provides a structural analysis of mining enterprises and proposes a concept of viewing them as anthropogenic mining complexes of various levels. The operating conditions of mining enterprises are marked by highly dynamic external factors, which retrospective analysis suggests will intensify in the future. The study systematizes adaptation tools for production systems according to the complex level. Extraction enterprises are recommended to use an adaptive management mechanism based on the systematic decomposition of extraction units. The proposed multi-level structure enables the justified selection of adaptation tools depending on the nature of the stimulating factors, allowing maximum effective response to them. The division of the mining system into complexes of different level allows, in accordance with the nature of the influence factor, to reasonably choose the optimal adaptation tools: changing the technological scheme of equipment operation, implementing a geoinformation system or changing the open-pit schedule etc.

It has been established that dividing the system into complexes of different levels allows for a justified selection of an adaptation tool depending on the nature of the stimulating factor. This approach enables adaptation at the necessary level, enhancing overall system resilience with lower costs, which is critically important for successful operations under uncertainty and constant change.

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

1. Introduction

In the current era of globalization and rapid transformations in the global economy, the mining industry faces a range of challenges stemming from a dynamic business environment. Price fluctuations for raw materials, ongoing technological advancements, and increasing demands for environmental safety and social responsibility all require enterprises to adapt swiftly and maintain strategic flexibility. Amid traditional inertia, mining enterprises often lag in adjusting production parameters to external economic conditions.

Adapting open-pit mining operations to these changes is critically important for ensuring enterprise resilience and competitiveness. The absence of effective adaptation tools can lead to reduced productivity, increased costs, and ultimately, a loss of market competitiveness.

The study and development of adaptation tools are relevant not only from a theoretical perspective but also due to the practical needs of the industry. These tools support the creation of new management models that account for the risks and uncertainties of the modern market, ensuring the long-term sustainable development of enterprises.

2. Methods

Previous research has introduced other components of the adaptation mechanism and outlined the algorithm for their use. Identifying the specific adaptation tools available to mining enterprises, as well as their systematization and classification, remains an important scientific task to enable their effective application in the future.

3. Results and discussion

Open-pit mining is a complex, multifactorial challenge focused on achieving dynamic equilibrium between subsystems and their parameters within an open mining cluster operating under uncertainty. This equilibrium is achieved by adapting the system to external disruptive factors [1, 2]. Taking a comprehensive, systems-based approach to mineral extraction reveals broader interconnections between economic entities at different levels. Numerous studies confirm a wide range of factors impacting key parameters of open-pit operations, often originating beyond the mine or even the mining enterprise itself. Consequently, structural analysis of mining enterprises has led to viewing them as anthropogenic mining complexes of various levels [3].

An anthropogenic mining complex of the first level is a technological equipment complex or mechanization system within an open-pit, mine, or technogenic deposit. Examples include the excavator-truck complex, truck-rail complex, and crusher-conveyor complex. A second-level anthropogenic mining complex is an individual extraction unit, formed by a set of workings that encompass first-level complexes, such as an open-pit, mine, stockpile, tailings pond, or technogenic deposit. A third-level anthropogenic mining complex represents a mining cluster–a group of interconnected mining enterprises within a region, sharing stable technological, logistical, economic, and financial links.

From a systems approach, at each level of a mining complex, the operations of a mining enterprise are influenced by external (uncontrolled) and internal (controlled) factors. Internal factors that can be adjusted at the system level of a selected level are termed adaptation tools. Naturally, the set of these tools varies across anthropogenic mining complexes of different levels. Notably, the number of internal, controlled factors increases as the hierarchical level of the anthropogenic mining complex rises.

At the level of first-level complexes, which handle direct operational tasks, adaptation can be achieved through optimizing production technologies, enhancing equipment, and improving working conditions. This allows for a rapid response to changes in the operational environment, helping to avoid downtime and disruptions. Key adaptation tools at this level include drilling and blasting parameters, blasting techniques and equipment, technical outfitting of machinery, work organization and personnel management, excavator positioning schemes, dump truck loading schemes, load flow management, raw material reserves, dumping schemes, and quality distribution management.

An example of implementing adaptation tools for a first-level anthropogenic mining complex can be seen in the industrial experiment at the Petrovskyi Open-Pit of PJSC "Central MPP" (Metinvest), where larger capacity buckets were installed for excavators working in overburden. Due to the challenging economic conditions in the country, the company cannot promptly upgrade its excavation and loading equipment fleet. However, the need to meet planned mining volumes necessitates production system adaptation. Replacing an 8 m³ bucket with a 10 m³ bucket significantly increases excavator productivity, reduces dump truck loading time, and could potentially reduce the main mining equipment fleet size.

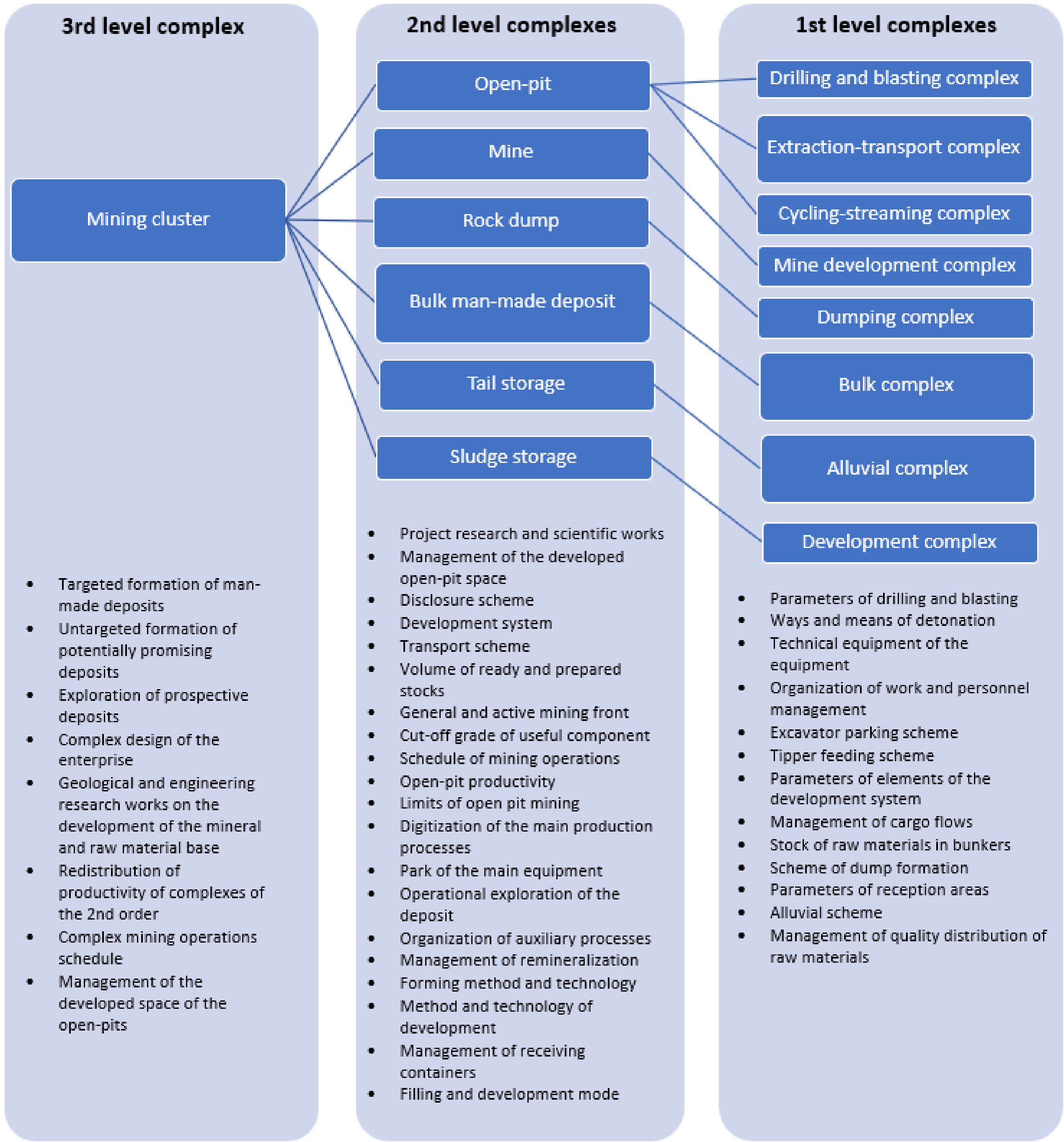


Figure 1 – Structural Diagram for the Use of Adaptation Tools

Another example is the replacement of the drill bit on the SBSh-250MNA drilling rig. Using an enlarged drill bit on rigs at the Petrovskyi Open-Pit of PJSC "Central MPP" for production drilling of blast holes can significantly boost equipment productivity without increased maintenance costs. Industrial experiments indicate that expanding bit size across the pit can increase overburden volumes by 504000 m^3 or reduce the drill fleet by two units, cutting maintenance and staffing expenses. The highest efficiency of a 250 mm bit is achieved in soft rock drilling over large blast blocks or short haul distances. International studies show that hydraulic system upgrades in excavators, as an adaptation example, can increase productivity by 18% [4].

Second-level complexes ensure coordination among various production elements, allowing operational changes to align with the cluster's overall strategies. They are essential components for integrating the activities of first-level complexes, coordinating their actions, and merging outcomes into a unified system. This enables adaptation not only to changes in the production process but also to macroeconomic and regulatory shifts affecting the entire cluster. Tools for second-level complexes include: design and research activities; management of the developed open-pit space; exposure scheme; mining system; transport scheme; volume of finished and prepared reserves; general and active mining front; minimum content of valuable components; mining schedule; open-pit productivity; boundaries of open-pit operations; digitalization of main production processes; main equipment fleet; operational exploration of the deposit; organization of auxiliary processes; management of secondary mineral formation; method and technology of formation; method and technology of development; management of receiving capacities; filling and depletion schedule.

An example of adaptation tools for a second-level complex is the implementation of a dispatch and automation system for main mining equipment at the open-pit of PJSC "Inhulets MPP." The introduction of an integrated software system that tracks the position of haul trucks in the open-pit and directs them to the available excavator helps reduce truck waiting time for loading by an average of 30–60 seconds. This leads to improved rhythm in the entire open-pit operation, reduces fuel costs, and increases equipment utilization efficiency. For the enterprises of the Kryvyi Rih Iron Ore Basin, digitalization of production has been examined in study [5] as an effective approach to enhancing the adaptability of the production system. The automated mining management system K-MINE has been analyzed as a software solution for this purpose. The study analyzes the main complexes of the system and their functional significance: geology, surveying, drilling and blasting, granulometric composition, optimal contours, and dispatching. It assesses the potential for increasing enterprise efficiency through automation systems. Since digitalization of production processes in a unified system spans several first-level complexes, this tool is categorized as a second-level complex.

Third-level complexes are responsible for the strategic management and development of the cluster, which includes the implementation of new technologies, innovation management, and the advancement of research initiatives. They enable the cluster's long-term adaptation to changes in the external environment, including market conditions, legislative shifts, and environmental challenges. Strategic adaptation at this level is critically important for maintaining the cluster's competitiveness in the global economy. Accordingly, the adaptation tools for a mining cluster include: targeted formation of technogenic deposits; untargeted creation of potentially promising deposits; exploration of prospective deposits; comprehensive complex design; geological and engineering surveys to develop the mineral resource base; redistribution of productivity among second-level complexes; mining regime of the cluster; and management of the developed space within the mining cluster.

An adaptation tool of the third level can involve managing developed spaces within an entire enterprise or adjacent enterprises within a mining complex. For example, overburden removed from the Hleyuvatskyi Open-Pit of PJSC "Central MPP" is placed in the developed space of Pit No. 2 of the same enterprise, fills funnels created by underground mining, and forms support prisms for the plant's tailings storage facility [6].

The well-known initiatives of mining and processing plants in Kryvbas involve utilizing tailings and sludge storage sites formed as a result of primary technological processes [7]. Such implementation of sustainable development approaches underscores the significant potential of adaptation tools and their impact, extending beyond the production system itself.

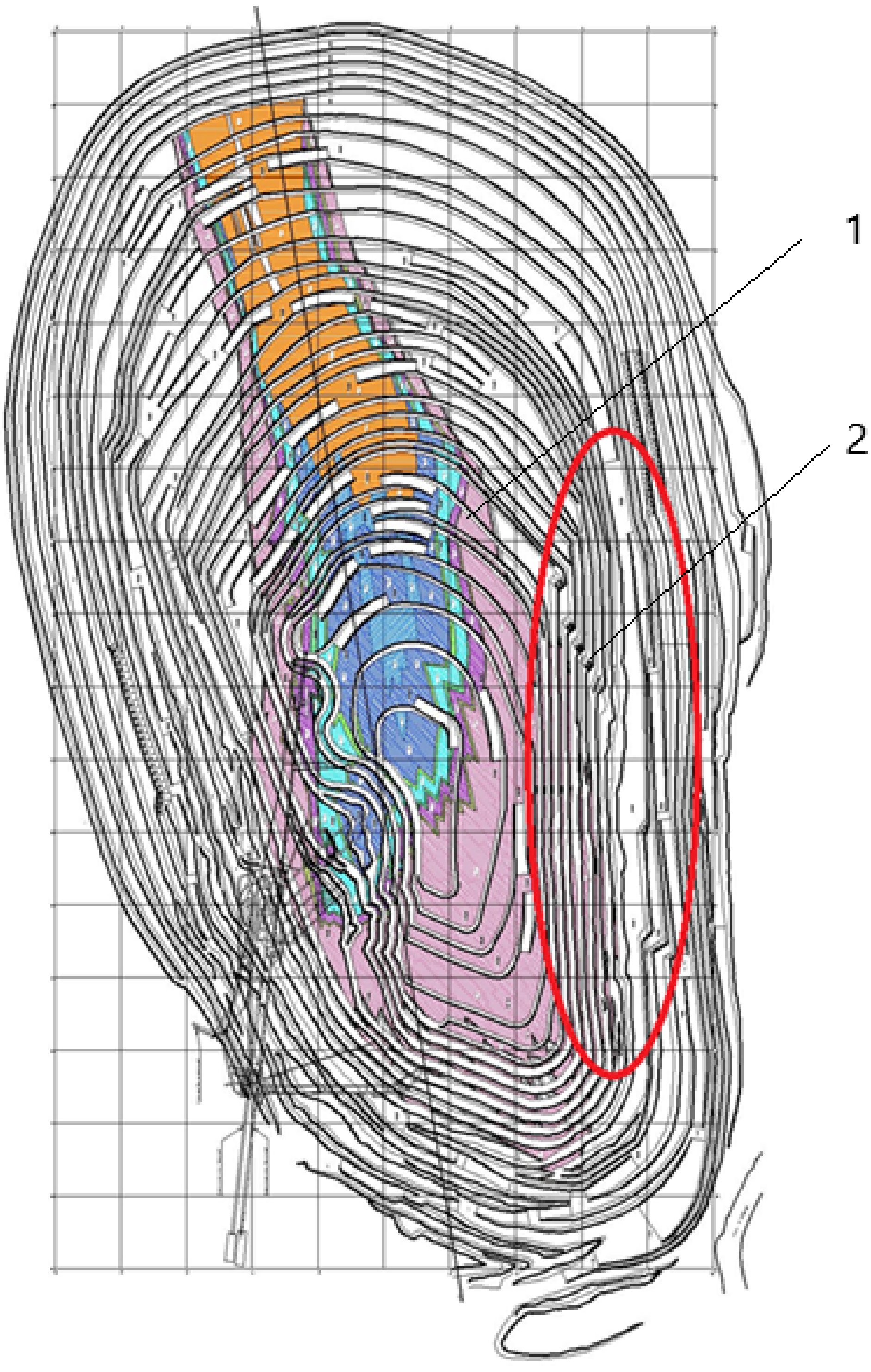
Referring to global examples of adaptation tools, at the highest hierarchical level is the extraction of cyanide as a byproduct at a gold deposit in Nevada, USA [8]. Another notable example is the use of mining and metallurgical waste for backfilling developed spaces in underground mining at the Bakyrchik mine in Eastern Kazakhstan. This technology not only reduces land area usage but also provides reliable backfill for developed spaces using secondary materials [9].

Another example of a third-level adaptation tool is the "open-pit-technogenic deposit" system operating at PJSC "Inhulets MPP." Within the Inhulets deposit, the talc schist seam has an inclined formation with an eastern dip. The seam thickness varies from 18 meters in the southern section to 64 meters in the northern part, with an average characteristic thickness of approximately 40 meters (Fig. 2).

The talc schists lie in alignment with the rocks of the first schist horizon and belong to the Skelevatska Suite, which is traced in the southern part of the deposit near the fold closure along both the eastern and western limbs. The chemical composition of the talc schists is presented in Table 1.

However, the established mining regime and the geometry of the talc schist layer do not allow for a consistent supply to meet consumer demand for talc. Therefore, a decision was made to form a technogenic deposit. According to preliminary assessments by the "Ukrgeology" trust, the total talc schist reserves at the Inhulets deposit amount to 20–22 million tons, with a bulk density of 2.6 t/m³. Of this, approximately 200000 tons are stockpiled in three sections of a separate waste rock dump, which now constitutes this technogenic deposit. The storage sections have a height of 3–3.5 meters with a slope angle of 34–38°. The hydrogeological and mining conditions allow for open-pit extraction of the technogenic deposit. The schists do not require beneficiation or processing. The talc schists are planned to be sold in their raw form to consumers in Ukraine. PJSC "Inhulets MPP" intends to develop them simultaneously across three sections, depending on demand for the raw material [10].

Given the low productivity rate of 20000 tons per year, the technogenic deposit is planned to be developed in a single shift during daylight hours, aligning with current raw material demand. The isolated nature of the technogenic material eliminates the need for capital and overburden work. Loading operations are expected to use a CAT-993K loader with a bucket capacity of 10 m³ or similar equipment. BELAZ-7540V (30 tons) and BELAZ-7547 (45 tons) dump trucks will handle internal transport, with subsequent transfer to railway transport.



1– ore body; 2 – talc schist zone

Figure 2 – Position of mining operations at “Inhulets MPP” as of 01.01.2022

Table 1 – Chemical composition of talc shale based on the results of detailed exploration

No	Chemical compounds	Content, wt.%
1	SiO_2	31.94–48.28
2	Al_2O_3	5.13–15.66
3	Fe_2O_3	0.14–8.43
4	FeO	3.48–13.92
5	MgO	14.28–27.74
6	CaO	0–7.7
7	TiO_2	0.321
8	SO_3	0.11
9	Na_2O	0.1
10	K_2O	0.1
11	others	8.47

The use of the technogenic deposit serves as a representative example of a third-level anthropogenic mining complex's adaptation to changing economic and geological factors. Additionally, the plant aims to ensure the rational use of natural resources, reduce the volume of overburden stockpiling, and free up 2.68 hectares of space within waste dumps.

However, the most significant adaptation tool for mining enterprises, and simultaneously proof of the formation of a unified mining cluster based on Kryvbas mining and processing plants, is the consolidation of the mineral resource bases of different enterprises. For instance, PJSC "Inhulets MPP" has accepted and processed over 110000 tons of ferruginous quartzites from JSC "Southern MPP". Implementing such an initiative requires, beyond allocating processing capacities, coordinating the transport departments of the plants, designating areas for raw and enriched ore storage, and conducting extensive scientific and engineering calculations.

A similar initiative was implemented by transporting ore from PJSC "Northern MPP" to the enrichment facilities of PJSC "Inhulets MPP". The stockpile operation involved designating two areas, operating on alternating days of the month. Ore was transported around the clock by road and rail, with continuous monitoring of quality characteristics. A CAT-993K pneumatic-wheeled loader was allocated to meet the needs of the stockpile.

Clearly, such decisions fall under third-level adaptation tools, as they involve various second-level anthropogenic mining complexes.

4. Conclusions

Currently, mining enterprises in Kryvbas exhibit unsystematic attempts to implement an adaptive approach at the level of anthropogenic mining complexes of all levels, confirming the mining industry's need for the proposed approach. Developing a systematic methodology and strategy for adaptive management of a mining cluster's operations will contribute to long-term improvements in the techno-economic indicators of mineral deposit development.

The proposed multi-level structure of a mining cluster offers significant advantages in terms of overall system adaptability. Dividing the system into complexes of different levels enables the justified selection of adaptation tools according to the nature of the influencing factor: changing the technological scheme of equipment operation, implementing a geoinformation system or changing the open-pit schedule etc. This approach facilitates adaptation at the required level, enhancing overall system resilience with lower costs, which is critically important for effective operations in conditions of uncertainty and constant change.

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ІНСТРУМЕНТИ АДАПТАЦІЇ ГІРНИЧОДОБУВНИХ ПІДПРИЄМСТВ ДО ДИНАМІЧНОГО СЕРЕДОВИЩА ГОСПОДАРЮВАННЯ

Григор’єв Ю., Луценко С., Григор’єв І., Рибалкіна І.

Анотація. Динаміка коливання попиту і цін на продукцію гірничодобувних підприємств характеризується високою волатильністю. При цьому динаміці коливань обсягів споживання мінеральної продукції притаманна значна інертність, але майже ніколи графіки кривих цих залежних показників не узгоджуються в часі. На фоні традиційної інертності гірничодобувних підприємств до подібної динаміки спостерігається стійке відставання параметрів виробничої системи до зовнішніх умов господарювання. На фоні традиційної інертності гірничодобувних підприємств до подібної динаміки спостерігається стійке відставання параметрів виробничої системи до зовнішніх умов господарювання. Адаптація гірничих робіт у кар'єрах до цих змін є критично важливою для забезпечення стійкості та конкурентоспроможності підприємств в динамічних умовах.

В роботі виконано аналіз досвіду гірничодобувних підприємств адаптуватися до змін некерованих факторів і виявлено переважно безсистемний підхід до впровадження механізмів адаптації. В статті наведено структурний аналіз гірничодобувних підприємств і запропоновано концепцію їх розгляду як антропогірничих комплексів різного порядку. Умови господарювання гірничо-видобувних підприємств характеризуються високою динамічністю зовнішніх факторів, а з огляду на ретроспективний аналіз, ця динаміка буде тільки посилюватися в майбутньому. Виконана систематизація інструментів адаптації виробничої системи відповідно до порядку комплексу. В своїй роботі добувні підприємства мають використовувати механізм адаптивного управління з урахуванням системної декомпозиції видобувних одиниць. Запропонована багаторівнева структура дозволяє обґрунтовано обирати інструменти адаптації залежно від характеру збуджуючих факторів, що дозволяє максимально ефективно реагувати на них. Розбиття гірничодобувної системи на комплекси різного порядку дозволяє відповідно до характеру фактору впливу обґрунтовано підібрати оптимальний інструменти адаптації: зміна технологічної схеми роботи обладнання, впровадження геоінформаційної системи, зміна режимі гірничих робіт тощо.

Встановлено, що розподіл системи на комплекси різного порядку дозволяє обґрунтовано обрати інструмент адаптації в залежності від характеру збуджуючого фактору. Пропонований підхід дозволяє здійснювати адаптацію на необхідному рівні, що підвищує загальну стійкість системи при менших витратах, що є критично важливим для успішної діяльності в умовах невизначеності та постійних змін.

Ключові слова: відкрита розробка корисних копалин, механізм адаптації, антропотехнічний комплекс, засоби адаптації, динамічне середовище