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Reusing underground mine space of closing mines

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ABSTRACT: The article addresses opportunity of the reuse, appearing in the process of closing coal-mining enterprises. It represents approaches of cost minimizing due to closing mines in the reusing closed mine object based on tentative example.

1 INTRODUCTION

Relevance of this work. Closing coal-mining enterprises in the Donbass is time-consuming process because of the specific technologies of coal getting in this region. In 2016, the Council of Ministers of the DPR came to a decision to close 22 unprofitable mines. As of 1.07.2017, 18 mines were liquidated, as of 1.11.2018, 3 unprofitable mines were shutted down too. However, upon the huge volume of unexercised space, leaving after liquidation, the question arises about the consideration of a certain type of resource. Notwithstanding, a huge structure of questions of what should be taken into account is the main problem, appearing during the mine liquidation.

The aim of this work is to indicate the possibilities of reusing underground space, consider the most promising areas of its reuse, as well as the construction of an economic and mathematical model to choose the best option for the reuse of mining enterprises.

V.A. Bezpflug and M.K. Durnin are researches of this sphere. The use of coalmine methane and various methods for its production are observed in a work of the previously mentioned authors, "Comparative economic evaluation of various technologies for utilization of coal mine methane" (Sorenkov V.M., Nedoluzhko V.N., Begicheva et al. 2012). Besides that, A.S. Kuznetsov in his work explained the advantages of using coal-water fuel (Kuznetsov A.S. et al. 2012).

The process of legal mine liquidation goes through several stages, namely:

1. Development of justifications for the feasibility of further mine exploitation and planning costs associated with its further use.
2. Implementation of design decisions.
3. Adoption of measures for employment and social protection of the dismissed, at the closure of the mine, personnel.
4. Creation of new jobs in regions where mine closure is envisaged.

We need elaborate a certain strategy of the mine liquidation: - to develop a socio-economic and hydrogeological forecast of the region, - justify the gradual closure of the mines, linking it with investment and financing opportunities, - to improve the regulatory framework, and study environmental problems of the mine liquidation (Panishko A.I. et al.2009).

Based on the above analysis, the process of liquidation of unprofitable mining enterprises can be characterized as having no the end in the future. It provokes a sufficiently high level of costs for maintaining the mine in the period of expansion work, reconstruction, construction of water drainage at the mining enterprise, overcoming social and economic consequences (costs of free coal supply, social safety net) (Levkin Yu. M. et al. 2004).

Physical closure provides for the dismantling of equipment, backfilling of trunks, ensuring drainage, the implementation of measures related to the elimination of unsuitable buildings and mine workings. The most labor-intensive things are coal loading bunkers, overhead structures, buildings of main ventilation fans, lifting machines and boiler rooms with monolithic reinforced concrete foundations. The last one should be destroyed to the level of minus 0.2-0.3 m from the ground level (Makarov A.A., Shevtsov N.R. et al.2002).

According to the intendended purpose, underground structures are conventionally divided into several main groups:

- Transport and hydraulic tunnels; structure underground system; power plants (mainly hydro); basic warehouses and refrigerators;
- Medical institutions, military facilities;
- Industrial enterprises;
- Tanks for the disposal of hazardous industrial waste;
- Oil and gas storage facilities;
- Tanks for drinking water;
- Objects of municipal facilities (pedestrian crossings, garages, collectors, etc.) (Panishko A.I. et al. 2009).

There are certain difficulties in the reuse of mine workings in coalmines, which are largely because the use of development systems with roof collapse or laying them with empty rock does not provide the preservation of the waste space. As a rule, it is difficult to use the capital mine workings (transport, ventilation, near-barrel yards) due to their insufficient cross-sections. In addition, it is hard to place efficient production flow lines in an extensive network of workings of small cross-section. In technological processes in gas mines, operations associated with high temperature (welding, soldering, etc.), should be excluded. There are high costs for the maintenance of mine equipment and the creation of safe working conditions (maintenance workings, organization of drainage, ventilation, power supply, the operation of lifting equipment, etc.).

Foreign experience in solving the problems of the mine's liquidation is achieved through economic, legal, and innovation-technical steps.

The implementation of economic and legal steps is carried out by changing the regulatory framework, based on objective economic laws and mechanisms (Panishko A.I. et al. 2009).

Therefore, in Poland, they made changes to the law on subsoil, which provided for mining companies to pay a special environmental fund - 10% with open pit and 3% with underground mining. This allowed to accumulate funds for the planned liquidation of mining enterprises.

In Germany, the practice of accumulating funds for the needs of liquidating mining enterprises designates the need for special licensing. At the same time, not only fines for environmental damage are paid, but also a license is purchased for carrying out activities that are potentially dangerous for the environment.

Thus, based on foreign experience, taking into account the unfavorable economic conditions in the Donbass, we can recommend tax-subsidy regimes that allow you to accumulate funds necessary for socially acceptable closure of mines. The trend in the application of innovative technical measures is reduced mainly to the spread of the rational use of waste underground space.

The most promising areas to reuse underground space of coalmines are:

- underground warehouses and storage facilities;
- peak reserve underground pumped storage power plants and hydro power plants;
- underground wind power.

2 ECONOMIC-MATHEMATICAL MODEL

An economic-mathematical model for the disposal of a mining enterprise has been developed to select the optimal reuse option.

$$C_1 + C_2 + C_3 \rightarrow min \quad (1)$$

$$k_1(k_2C_2 + C_3) \leq R$$

$$C_1 + k_1(k_2C_2 + C_3) \leq L$$

$$\frac{0.53(0.57C_1) + 0.53(0.57C_2) + 0.53(0.57C_3)}{n} \geq \frac{0.53(0.57\Sigma C_i^0)}{N}$$

$$\Sigma C_i^0 \geq 0$$

$$\Sigma C_i \leq \Sigma C_i^0$$

$$\Sigma C_i \leq R$$

Where C1, C2, C3 - the costs of designing, developing and operating a new production;

R - revenues from the exploitation of new mastered production;

L - the costs associated with overcoming the effects of "wet" mine;

S - costs associated with overcoming the social consequences of the mine's liquidation;

N, n - the number of workers in accordance with redundant workers at the closure of the mine and employed workers to a new production;

α, β - shares in the costs of mastering and operating a new production attributable to the wages of workers;

k1 – coefficient, which is taking into account the increase in costs in connection with the geological conditions and the life extension of the underground structure;

k2 – coefficient, which is taking into account the increase in operating costs in connection with the increase in the depth of work.

Consider an example of using this model with the following conditional data. Based on the condition, the company allocated $ 250,000 for the introduction of new production. The planning department calculated the following values presented in Table 1.

Let's find an optimal solution of the conditional problem using the Excel function "Search for solution". We see that the amount of expenses is $ 279,320. The componentwise representation of expenses, in it turns, is represented by the following indicators:

Table 1. Conditional data for solving the optimization problem.

№	Denomination	Indicator name	Value, thousand. $
1	2	3	4
2	C1	The cost of designing a new production	30.00
3	C2	The cost of mastering a new production	120.85
4	C3	The cost of operating a new production	128.47
5	R	Revenues from the exploitation of new production	1,000.00
6	L	Costs associated with overcoming the effects of "wet" mine	1,000.00
7	n	The number of employees taken to the new works	50.00
8	N	The number of workers laid off due to the closure of the mine	50.00
9	S	Costs associated with overcoming the social consequences of the mine's liquidation	84.38

* conditional data has been formed on the basis of research of Donetsk institute for design organization of mine construction and enterprises of the construction industry, which was reflected in the research work 'Development of proposals on the possibility of using underground spaces in connection with the closure of mines'.

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Optimized cost by elements	C1	C2	C3
Materials cost	$ -	$ 10,00	$ 15,00
Miscellaneous expenses	$ 30,00	$ -	$ -
Manufacturing expenses	$ -	$ 50,00	$ 50,00
Labour expenses	$ -	$ 35,00	$ 37,00
Depreciation charge	$ -	$ 15,00	$ 15,00
Unified social tax	$ -	$ 10,85	$ 11,47
Sum total, prime cost	$ 30,00	$ 120,85	$ 128,47

Figure 1. The componentwise representation of expenses before optimization.

Profitability of expenses will be equal to $ 280, profitability of revenue - $ 3580, which, in turn, diagram demonstrates us that $ 1.000 of income accounted for $ 280 in expenses and $ 1,000 in expenses — $ 3,580 in income.

It is necessary optimally to redistribute the amount of expenses that the company is prepared to incur with minimal losses. With the help of the function "Search for solution", we get the following values:

The solution of an optimization issue showed that it would be more reasonably to use mixed method with drawing on contract organizations in implementation of new contracting organizations to preserve the optimality of the plan, but with a decrease for expenses. You can consider the option of re-using materials to save the use of material resources. It is necessary to increase the productivity of workers engaged in the development and operation of a new production to reduce the value of the wage parameter. Hence, if the salary is dropping, the unified social tax will be falling too.

We also see that because of solving the optimization model, the profitability of expenses decreased by $ 30 from each thousand revenues, and the profitability of revenue rose by $ 420 from each thousand expenses, which undoubtedly indicates that the optimization of expenses on this model favorably affects the redistribution the amount of the planned expenses.

In Table 2 we can see that all specified constraints have been accomplished, and the absence of the given gradient says that when a parameter is included in the plan that the optimization model does not offer, to a large extent, the value of the objective function (in this case, the sum of expenses) will not be changed.

The financial statement, which is shown in Table 3, proves the results of research by many scientists who dealt with the problems of the coal-mining enterprises elimination in particular, the most significant and substantial component in the total costs will be the parameters, which are responsible for eliminating the socio-economic aspect.

Optimized cost by elements	C1	C2	C3
Materials cost	$ -	$ 7,70	$ -
Miscellaneous expenses	$ 30,00	$ 1,32	$ 0,47
Manufacturing expenses	$ -	$ 47,56	$ 47,42
Labour expenses	$ -	$ 31,66	$ 33,64
Depreciation charge	$ -	$ 15,00	$ 15,00
Unified social tax	$ -	$ 9,81	$ 10,43
Sum total, prime cost	$ 30,00	$ 113,05	$ 106,95

Figure 2. The componentwise representation of cost after optimization.

Table 2. Sustainability report.

Box	Name	The final value	Reduced gradient
1	2	3	4
$K$15	Material cost C2	7,696131868	0
$L$15	Material cost C3	0	0
$K$16	Miscellaneous expenses C2	1,319243077	0
$L$16	Miscellaneous expenses C3	0,46907931	0
$K$17	Manufacturing expenses C2	47,56181722	0
$L$17	Manufacturing expenses C3	47,42031796	0
$K$18	Labour expenses C2	31,656455	0
$L$18	Labour expenses C2	33,63622406	0

Table 3. Results report.

Box	Name	Meaning of the box	Formula	Condition	Access
1	2	3	4	5	6
$E$10	Parameter non-negativity conditions 1	30,00	$E$10>=$G$10	No binding	30,00
$E$11	Parameter non-negativity conditions 2	113,05	$E$11>=$G$11	No binding	113,05
$E$12	Parameter non-negativity conditions 3	106,95	$E$12>=$G$12	No binding	106,95
$E$13	Conditions whereby the optimized parameters will be less than the planned one 1	30,00	$E$13<=$G$13	Binding	0
$E$14	Conditions whereby the optimized parameters will be less than the planned one 2	113,05	$E$14<=$G$14	Binding	0
$E$15	Conditions whereby the optimized parameters will be less than the planned one 3	106,95	$E$15>=$G$15	Binding	0
$E$16	Production breakeven	250,00	$E$16<=$G$16	No binding	750,000001
$E$7	Comparative breakeven	337,53	$E$7<=$G$7	No binding	662,4743495
$E$8	Comparative cost value, linking with the choice of liquidation method	367,53	$E$8>=$G$8	No binding	632,4743495
$E$9	Social and economic aspect to attract redundant workers in the time of liquidation to new ways of works	1,51	$E$9>=$G$9	Binding	0,00
$F$3	Choice criterion	$250,00	$F$3=250	Binding	0
$K$18	Labour expenses C2	$31,66	$K$18>=$C$31	No binding	$1,66
$L$18	Labour expenses C3	$33,64	$L$18>=$C$31	No binding	$3,64

Thus, the performance review of the mine workings in the closed coalmines to assess its reuse, it will be carried out in several stages in the following sequence:

- select options for reuse of mine workings,
- considerate the mine network of workings and the selection of those that are technically suitable for the chosen direction of use,
- study the impact of the surrounding geological environment on the selected workings, their assessment of stability, depth, increase in service life,

- study of the state of mine workings in terms of the need for their repair and re-equipment for new production, taking into account the chosen direction of reuse,
- economic assessment of the chosen direction and place (selected in the process of analysis of mine workings) of reusing underground space in the coal mine according to the "cost minimization" principle . That is, the project self-sufficiency, in order to justify the "dry" or combined preservation of the mine and save part of the fund of jobs.

World experience in the use of underground space, which does not participate in coal mining, suggests that the introduction of such technologies is possible in the countries of Eastern Europe and Asia. Mine workings, which have no prospects for possible further exploitation for their intended purpose, can be used as a storage of household and industrial non-toxic waste.

The analysis, forecast and evaluation of a part of the mine survey monitoring system of a coal mining enterprise, which can be used later for multi-purpose, are necessary requirements (Golovneva, E.E. et al. 2002).

As a result, we can conclude about the technical complexity and, often, the economic inexpediency of locating production of industrial products in mining. Although there are contradictions, regarding the mine reuse, that have not been solved at the moment, we propose the following concept of reusing underground space, which consists of several steps presented in Figure 3:

- At the first stage - inventory and systematization of all mine workings are performed;
- At the second stage - the selection of workings promising for the placement of the national economy objects in them is realized;

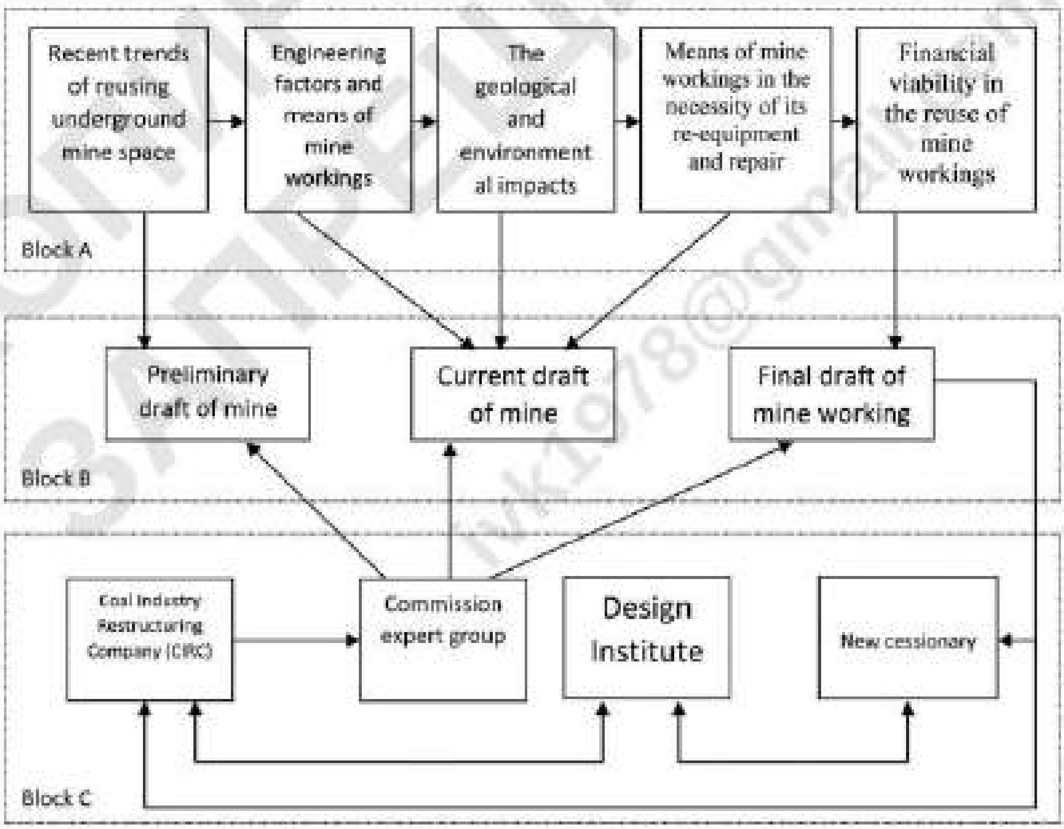

Figure 3. Flow chart of the strategy to reuse underground space.

- At the third stage - the workings are classified according to the main directions of use and are assessed according to the specific requirements of the objects placed in such workings.

The presented economic-mathematical model allows choosing the optimal variant of reusing underground space of a closing mine according to the presented strategy of determining the optimal plan.

It should be noted that the use of this model should not be authoritative when you decide to reuse of underground space. This strategy performs only a supporting function for the planning section and technical departments.

Together with the use of an optimization model, which has been built on the presented strategy, you can get quite good results on the profitability of using the new production.

3 CONCLUSIONS

Based on the above, we can make conclusion that the closure of the mine is an expensive, lengthy and difficult process with many attendant factors. Alongside this, it is implementable to receive economic benefits from a closed mine, allowing to minimize the cost to liquidate an enterprise. For example, it is for the production of electricity or for the creation of special storage facilities. Using the developed economic-mathematical model in completed with the Excel function “Search for solution”, it is viable to calculate the economic feasibility and choose the best option to reuse the underground space of a liquidated mine. Reports on solution of the optimization model will help to analyze the resulting model and improve it. According to the results of our calculations, using the underground space of mines as warehouses for materials of construction industries and the burial of mining waste is the appropriate way for Donetsk region. This is due to a very large development depth of 700-1000 m.

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