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Assessment of the using a mobile crushing and sorting plant investment attractiveness at the development of construction material quarries

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Abstract

Purpose. To establish the influence of the quarry depth at the construction materials deposit mining on the payback period of investments when using the haulage mining system (HMS), cyclic flow technology (CFT), and mobile crushing and sorting plant (MCSP) with a comparison of its efficiency.

Methods. The research used discounted value of cash flow methods to determine the company's net present value (NPV) and the investment payback period. When establishing a mining enterprise's technical and economic performance indicators, the present value factor of future costs and profits was considered.

Findings. According to the total discounted cash flow value indicator, the technological scheme using a mobile crushing and sorting plant is the most attractive in the quarry depth range of 50-150 m. According to this indicator, it was established that it is better in comparison with the schemes of the haulage mining system and cyclic flow technology, respectively, by 19 and 26% at a quarry depth of 50 m. When the quarry depth increases from 100 to 150 m, the efficiency of the MCSP scheme in terms of the indicator of total cash flow will be 5.2 and 5.8 times exceeding the indicators of the CFT and HMS schemes, respectively.

Originality. The impact of the quarry depth mining on the indicators of the cash flow discounted value, the net income of the enterprise NPV, and the payback period of the investment was determined, which allowed to determine the most effective technological scheme at the given quarry productivity of 1.6 million m^3/year. It was determined that using a scheme with a mobile crushing and sorting plant compared to other schemes in the cash flow total cost indicator is more effective by 17-28% at a quarry development depth of 50 m. At the same time, at a quarry depth of 150 m, the effectiveness of the technological scheme of MCSP by the enterprise total profit indicator increases significantly to 2.0 and 3.5 times superior to the CFT and HMS schemes, respectively.

Practical implications. The conducted research is essential when choosing technological schemes for exploiting construction raw materials quarries when their development depth increases. This result is especially relevant for mining companies that produce crushed stone, where mobile crushing and sorting plants can significantly improve economic efficiency.

Keywords: *quarry, construction material deposits, cyclic flow technology, mobile crusher, investment payback period*

1. Introduction

The development of construction raw materials deposits involves a significant list of technological processes, the proper organization of which depends on the functioning effectiveness of the mining enterprise [1]. The design decisions are evaluated based on the calculation of the obtaining finished crushed stone products and preference given to the technological scheme, which ensures the minimum indicators [2].

The main difficulty in assessing quarries' technical and economic performance at the development of construction deposits is the increase in costs during the life cycle of the enterprise [3]. This statement is due to the constant deepening of the quarry and the necessary increase in the distance of mining mass haulage from mining and overburden benches to the surface [4].

Since the development of the quarry benches takes place sequentially [5], the minimum costs for the extraction of a mineral unit will fall in the initial years of the enterprise operation [6], while the increase of the expenses will occur when the mining benches are lowered for each new horizon [7]. At the same time, the company's revenue from the sale of finished products will remain unchanged at fixed quarry productivity [8]. Thus, there is a need to compare the effectiveness of technological schemes, considering current and future costs [9].

This approach will make it possible to correctly determine the cash flow value during the project implementation period. This is especially important when improving technological solutions to increase the efficiency of construction material quarries at depths of more than 100 m [10]. The

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main goal of enhancing technological schemes is to reduce the volume of haulage work of the enterprise [11], which falls on dump trucks, through the introduction of cyclic flow technology, as well as the arrangement of mobile crushing and sorting plants on the concentration horizons of the quarry [12]. These platforms will be used where the consumer haulage load occurs [13].

Thus, comparing the existing technological scheme at the quarry with the proposed solutions should take place during a specific period for the project implementation [14]. The conducted studies will make it possible to establish the indicators of the discounted value of cash flow and the profit of the enterprise NPV and to evaluate the investment attractiveness of quarry technological development schemes by determining the investment payback period [15].

The studies in [5] are devoted to establishing the maximum depth of granite quarries, considering the location of internal dumps. The proposed solutions make it possible to increase the efficiency of mining operations and achieve an economic effect when the quarry reaches the maximum depth. The developed methodology considers the indicators of resource and land conservation during the operation of a quarry for the production of crushed stone products. At the same time, the proposed solutions do not allow for comparing the effectiveness of technological schemes for developing a quarry with a given productivity when using mobile crushing and sorting plants.

The work [9] presents research results that connect mining operations efficiency increasing at developing a granite quarry with the subsequent production of crushed stone products. The proposed solutions involve attracting new areas of the deposit to ensure the growing demand for products. The practicality of new investments in infrastructure creation, equipment purchase, and new staff employment has been established. However, the studies that were performed should have considered the issue of demonstrating the effectiveness of the latest technological solutions in the existing conditions of quarry operation.

The results of work research [15] allow the investor to obtain a tool for decision-making in the development of construction material quarries, taking into account the economic assessment of a realistic scenario. Due to the proposed methodology, a risk analysis was performed, considering many uncertainty scenarios. The developed solutions, in turn, need to consider the dynamics of the increase in the deposit depth during operation period development, making it impossible to determine the most effective technological scheme among possible options.

In studies [16], the maximum net profit for determining the final quarry depth is taken as the primary criterion for evaluating the effectiveness of technological solutions. The obtained results prove the effectiveness of the depleted minerals' involvement in the production process, which extends the field's life and increases the profit level by 10%. A shortcoming of the developed methodological recommendations for economic evaluation is the analysis's need for possible replacement of existing development technological schemes.

Carried out research [17] made it possible to establish that not only capital costs determine the production cost of crushed stone but also the costs of blasting, the cost of drilling and maintenance of equipment, and the costs of destroying oversized items. According to these remarks, research results confirm the possibility of increasing the efficiency of quarries by reducing operational costs. However, these recommendations have little impact on the choice of technological schemes; there is mining mass preparation work before excavation using the same technology. At the same time, the indicator of the enterprise haulage operation is not considered when quarry deepening.

Work research [18] aims to increase the efficiency of mineral extraction and processing used as fine aggregate in various industries. The disadvantage of the considered work is the need for proposals to improve the efficiency of mining operations to reduce aggregates' costs.

The performed analysis of research works confirms the need to determine the effectiveness of technological schemes for the development of quarries [19] using indicators of the cash flow discounted value and enterprise profit NPV, which allows for determining the payback period of investments and choosing the most effective project solution [20]. However, the central part of the research is devoted to the issue of the return on investment for mining enterprises [21] on the development of ore materials, which involves high costs for the enrichment of raw materials and almost eliminates the issue of increasing costs for the delivery of raw materials associated with the quarry deepening [22].

When solving the identified problems, the goal of the research was formulated; it consists of establishing the influence of the mining depth of a deposit of construction materials on the investment payback period when using the haulage mining system (HMS), cyclic flow technology (CFT) and mobile crushing and sorting plant (MCSP).

To achieve the goal of the research, the following tasks were performed:

– to determine the influence of the quarry depth on discounted cash flow distribution during 10 years of operation, taking into account the technological scheme of working out the quarry;

– establish the cash balance of the enterprise (NPV) when developing a quarry with a given capacity and variable depth;

– to determine the efficiency of the haulage mining system schemes, cyclic flow technology, and mobile crushing and sorting plant based on the indicators of the cash flow discounted value and enterprise profit (NPV);

– to compare the effectiveness of technological schemes according to the indicator of the investment payback period from the mining depth of a construction material quarry, taking into account the productivity of 1.6 million m^3 with a change in mining depth from 50 to 150 m.

2. Research methods

During the research, cash flow discounted value methods were used to determine the company's NPV profit and the investment payback period. When establishing a mining enterprise's technical and economic performance indicators, future costs and profits' present value are considered. The analytical research method was used to establish the dependence of the discounted cash flow value and the investment payback period on the depth of deposit development at a given quarry productivity.

The primary technological schemes used in quarries to develop construction raw materials at the crushed stone products manufacture are presented in Figure 1.

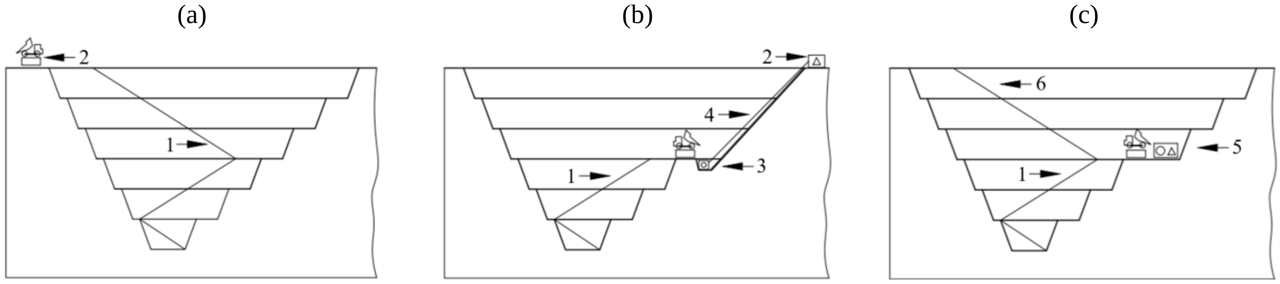

Figure 1. The central technological schemes at the construction material deposits development: (a) haulage mining system (HMS); (b) cyclic flow technology (CFT); (c) mobile crushing and sorting plant (MCSP); 1 – road for quarry vehicles; 2 – transshipment point; 3 – crushing plant; 4 – inclined conveyor; 5 – mobile crushing and sorting plant; 6 – road for consumer haulage

According to the method of establishing the investment attractiveness of the proposed schemes for developing construction material quarries, the specified period of enterprise operation is determined in the first order. During the research in this work, the term of the development main stage was accepted – 10 years, while the preparatory stage before the mining work period will be one year.

When analyzing each technological scheme's technical and economic indicators, a quarry for developing construction material with a constant annual productivity of 1.6 million m^3 is investigated [1]. The constant value of the productivity indicator during the deposit operation allows for the correct comparison of the capital and operating costs during the extraction of raw materials with the subsequent establishment of the cost of obtaining crushed stone products, taking into account the depth of the deposit development.

At the first stage of establishing investment attractiveness, a comparison of technical and economic indicators of three technological schemes (Fig. 1), determined in previous studies [1], is performed. These include a haulage mining system (TRS), cyclic flow technology (CFT), use of a mobile crushing and sorting plant in the middle benches of the quarry (MCSP).

According to previous studies, each scheme's initial technical and economic indicators were established for calculating cash flow during developing a 50-m-deep quarry (Table 1).

Table 1. Initial data for establishing cash flow indicators during the development of a 50-m-deep quarry

Types of expenses	Technological scheme		
	HMS	CFT	MCSP
Capital expenses, million USD			
Excavation and haulage	4.4	3.8	3.8
Crushing	2.9	2.2	1.1
Additional equipment	0.4	0.3	0.2
Infrastructure	0.2	0.2	0.1
Total	7.8	6.5	5.4
Operational expenses			
Excavation of minerals, USD/m^3	2.3	2.6	3.2
Excavation of overburden, USD/m^3	0.3	0.3	0.4
Crushing, USD/m^3	1.7	1.9	2.3
Overhead costs, million USD/year	0.5	0.5	0.5

To evaluate the cash flow of an enterprise that operates a quarry for construction raw materials development and manufactures crushed stone products for 10 years, in addition to capital and operating costs for each of the three technological schemes, it is necessary to take the average indicators of the selling crushed stone products cost and the natural density of crushed stone to determine the weight of the commodity products.

During the determination of cash flow, the average cost of crushed stone products was taken as 4.3 USD/t, while the natural density of the mineral is 2.7 t/m^3. The annual volume of overburden works is 0.2 million m^3, with an overburden coefficient of 0.12.

To determine the further influence of the quarry depth and the efficiency of the development of technological schemes of a construction material deposit based on the discounted cash flow indicator, the technical and economic indicators of the enterprise operation during the quarry mining at a depth of 100 m were established. At the carrying out of research, the quarry productive capacity in aggregates was taken as in previous calculations in the amount of 1.6 million m^3/year. The rest of the initial data for establishing the dependence of discounted cash flow (NPV) on the development year of a 100-m-deep quarry using three technological schemes are shown in the Table 2.

Table 2. Initial data for establishing cash flow indicators during the development of a 100-m-deep quarry

Types of expenses	Technological scheme		
	HMS	CFT	MCSP
Capital expenses, million USD			
Excavation and haulage	6.1	4.4	4.4
Crushing	2.9	3.8	1.1
Additional equipment	0.4	0.4	0.3
Infrastructure	0.2	0.2	0.1
Total	9.7	8.9	6.0
Operational expenses			
Excavation of minerals, USD/m^3	3.2	3.0	2.3
Excavation of overburden, USD/m^3	0.4	0.4	0.3
Crushing, USD/m^3	2.3	2.2	1.7
Overhead costs, million USD/year	0.5	0.5	0.5

Setting the indicators of discounted cash flow according to technological schemes of HMS, CFT, and MCSP for a quarry with a depth of 100 m was carried out in the same sequence as for a depth of 50 m. When setting indicators of discounted cash flow, the average cost of crushed stone products, the mineral's natural density, and the annual overburden volume did not change.

Last but not least, when determining the impact of the developing technological scheme of construction material deposits on the discounted cash flow indicator, the technical and economic indicators of the quarry operation with a depth of 150 m were considered. The initial data for obtaining discounted cash flow (NPV) indicators during 10 years of quarry development with constant production with a 1.6 million m^3/year capacity when using three technological schemes are shown in the Table 3.

Table 3. Initial data for establishing cash flow indicators when developing a 150 m deep quarry

Types of expenses	Technological scheme		
	HMS	CFT	MCSP
Capital expenses, million USD			
Excavation and haulage	7.6	5.0	5.0
Crushing	2.9	7.5	1.1
Additional equipment	0.5	0.6	0.3
Infrastructure	0.3	0.3	0.2
Total	11.2	13.4	6.6
Operational expenses			
Excavation of minerals, USD/m^3	4.5	4.1	3.1
Excavation of overburden, USD/m^3	0.4	0.3	0.2
Crushing, USD/m^3	2.3	2.1	1.6
Overhead costs, million USD/year	0.5	0.5	0.5

According to the initial data (Table 3), the most significant capital costs, taking into account geological exploration, are observed with the technological scheme of the CFT and amount to 14.1 million USD, which is 1.18 times higher than under the HMS scheme and 1.93 times higher than under the MCSP. First, such costs are caused by the need to build steep trenches to place inclined conveyors that ensure the increasing rock haulage distance.

The developed methodical approaches to determining the technical and economic efficiency of the considered technological schemes application at the development of a quarry will allow establishing the enterprise discounted cash flow in the next 10 years of operation, to determine the cash balance of the enterprise and to calculate the investment payback period taking into account the quarry depth. The obtained results will provide an opportunity to investigate the change in the investment attractiveness of the proposed technological schemes when the depth of quarry development of a given productivity is increased from 50 to 150 m.

3. Results and discussion

3.1. Establishing discounted cash flow of the enterprise

According to the data given in the methodology, an analysis of cash flow was performed for three projects, which include the use of three technological schemes: haulage mining system, cyclic flow technology, and use of a mobile crushing and sorting plant in the middle benches of the quarry. A detailed analysis of cash flow for the technological scheme using the haulage mining system is given in Table 4.

According to the cash flow analysis (Table 4), it was established that the volume of total investments in the preparatory year for operation according to the HMS technological scheme is 8.5 million USD, including capital expenditures and field exploration. The enterprise's annual revenue at the given technical and economic indicators will amount to 14.8 million USD, and operating costs will be 7.0 million USD. Considering the remaining indicators, the cash flow according to this technological scheme will be from 4.1 to 4.6 million USD, depending on the year of quarry operation.

Table 4. Analysis of the cash flow of the project (million USD) during the application of the HMS technological scheme at the development of a quarry with a depth of 50 m and a productivity of 1.6 million m^3

Indicators	Year of development											Total, million USD
	-1	1	2	3	4	5	6	7	8	9	10	
Receipts	0.0	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	148.1
Operating costs	0.5	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	70.4
Income	-0.5	7.8	7.8	7.8	7.8	7.8	7.8	7.8	7.8	7.8	7.8	77.7
Depreciation of tangible assets	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.0	7.8
Amortization of intangible assets	0.0	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.7
Unaccounted for losses	0.0	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	7.4
Taxable income	-1.3	6.2	6.2	6.2	6.2	6.2	6.3	6.3	6.3	6.3	7.1	61.8
Tax	-0.7	3.2	3.2	3.2	3.2	3.2	3.3	3.3	3.3	3.3	3.7	32.1
Profit	-0.6	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.4	29.7
Depreciation of tangible assets	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.0	7.8
Amortization of intangible assets	0.0	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.7
Unaccounted expenses	0.0	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	7.4
Field exploration	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7
Capital expenditure	7.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.8
Residual value	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cash flow, million USD	-8.4	4.6	4.6	4.6	4.6	4.6	4.5	4.5	4.5	4.5	4.1	37.1

According to a similar method, an analysis of cash flow was performed for technological schemes using cyclic flow technology and a mobile crushing and sorting plant in the middle benches of the quarry.

For a correct comparison of cash flow according to different technological schemes and years, it is necessary to use the discounting method, which will allow the influence of the time factor on economic indicators to be considered. When establishing the net present value of cash flow (NPV), a discount rate of 10% was used; this corresponds to the average percentage of keeping money on deposit.

The results of the discounted annual cash flow (NPV) analysis depending on the year of development of a quarry with a depth of 50 m according to three technological schemes are shown in Figure 2. According to the established results (Fig. 2) for a quarry depth of 50 m, the most significant cash flow was recorded using the technological scheme of the MCSP. It is worth noting that even during the preparatory work before putting the quarry into operation, the total costs according to the HMS technological scheme will amount to more than 8.3 million USD, while the application of the MCSP scheme will reduce the expenses specified by 1.4 times to 6.0 million USD.

According to the technological scheme of the CFT, costs at the preparatory stage are 7.1 million USD, which is 1.2 times higher than the MCSP scheme; however, according to this indicator, this scheme is 1.16 times more effective than the HMS scheme.

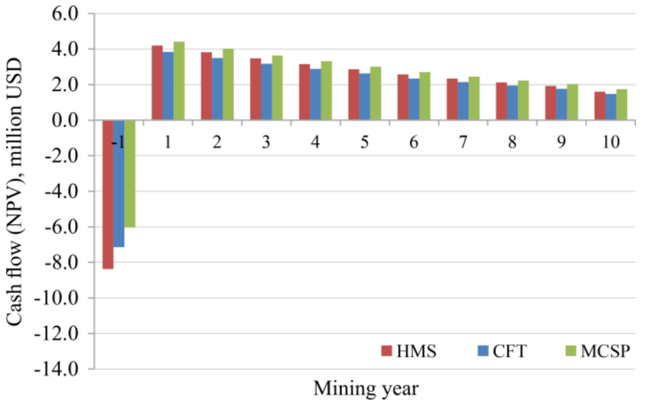

Figure 2. Dependence of the discounted cash flow indicator from the year of quarry development with a depth of 50 m

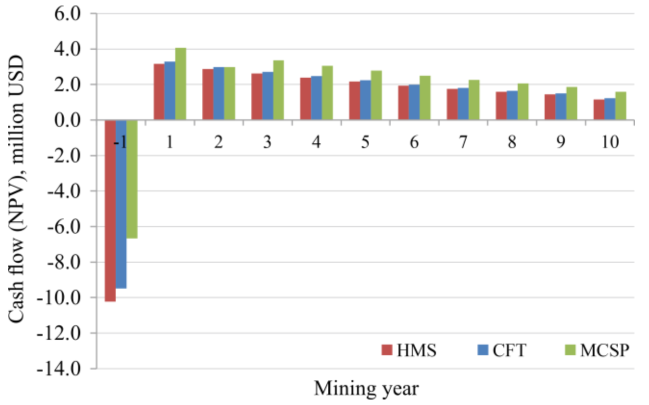

Figure 3. Dependence of the discounted cash flow indicator from the year of quarry development with a depth of 100 m

It was established that during the investigated period of 10 years of quarry exploitation, with the use of accepted technological schemes, the most significant cash flow was recorded for HMS and MCSP technologies, since at a development depth of 50 m under these decisions, the enterprise can receive the highest profits due to the lower production products cost in comparison with the CFT scheme.

The total cost of NPV cash flow at a quarry development depth of 50 m with a productivity of 1.6 million m^3 using the HMS technological scheme will be 19.7 million USD, CFT – 18.5 million USD, and MCSP – 23.5 million USD. However, with a further increase in the depth of quarry development, the company's cash flow will decrease due to increased expenses and the cost of manufacturing finished products.

According to the established indicators (Table 2), the volume of total investments in the preparatory year for operation using the HMS technological scheme is 10.4 million USD, which must be concentrated to pay off capital costs and conduct additional exploration of the field in the preparatory year for quarry operation. For the CFT scheme in the preparatory year, the total costs will be 9.6 million USD, 1.43 times more than the technological scheme of MCSP, where costs will amount to 6.7 million USD.

Annual operating costs at the HMS scheme will amount to 9.3 million USD, 5% more than the CFT scheme, where costs will reach 9.0 million USD. The most effective, according to this indicator, is the technological scheme of the MCSP, where the operating costs are 7.0 million USD, which is 1.33 and 1.27 times less than in the HMS and CFT schemes, respectively.

Considering all established indicators, the annual cash flow according to the HMS technological scheme will be 3.0-3.5 million USD. The CFT scheme will fluctuate between 3.2-3.6 million USD, while using the MCSP scheme will significantly increase to 1.4-4.5 million USD annually.

The summarized results of the cash flow comparison according to the technological schemes of HMS, CFT, and MCSP when working out a 100 m deep quarry using the discounting method are shown in Figure 3.

The established influence of the deposit development year on the indicator of discounted cash flow at a quarry depth of 100 m (Fig. 3) allows us to state that the most significant capital costs correspond to the HMS scheme. In contrast, according to this indicator, the MCSP scheme can be considered the most effective. According to the indicator of discounted cash flow, the HMS scheme is the least effective.

It was determined that during the 10 years of the quarry operation, according to the considered technological schemes, the most significant cash flow was recorded for the CFT and MCSP technologies, which differs from the indicators obtained during the development of a 50-m-deep quarry. Due to reduced operating costs, the CFT technological scheme becomes more attractive according to HMS; however, in the rest, it is inferior to MCSP.

When developing a quarry with a depth of 100 m, the total value of NPV cash flow when using the HMS technological scheme will be 10.9 million USD, CFT – 12.4 million USD, and MCSP – 19.9 million USD. Thus, the total cash flow of the CFT scheme increased by 1.14 times compared to the MCSP scheme. It was also established that when the quarry depth is doubled from 50 to 100 m, the total cost of NPV cash flow decreases by 1.2-1.8 times, depending on the technological scheme, which is associated with an increase in the company's costs at constant revenue indicators.

In further studies, primary attention is paid to the influence of the technological scheme choice on the indicators of discounted cash flow when the quarry depth increases to 150 m. The importance of these studies is emphasized because today, a significant number of construction raw material quarries exceed a depth of 100 m, negatively affecting the formation of a competitive price of commodity products.

According to the previously established indicators (Table 3), the highest operating costs for developing a quarry with a depth of 150 m are recorded with the HMS scheme. They make 11.5 million USD, which is 9% higher than the CFT scheme's costs of 10.5 million USD. The lowest operational costs for this quarry depth are observed in the technological scheme of the MCSP, with an indicator of 7.9 million USD. This is 1.45 times less than in the HMS scheme and 1.32 times less than in the CFT. Thus, when the depth of the quarry is increased to 150 m, the MCSP scheme's effectiveness in terms of operating costs increases compared to other schemes.

Determination of annual cash flow indicators for each technological scheme at a development depth of 150 m made it possible to establish that according to the HMS scheme, it will range from 2.0 to 2.4 million USD depending on the year of development, while when applying the CFT scheme, its value will vary from 2.4 to 2.9 million USD. The highest cash flow values were recorded for the technological scheme of the MCSP, which ranged from 3.7 to 4.0 million USD per year. This is due to the lower capital and operating costs achieved under the scheme of MCSP.

The established indicators of discounted cash flow by year during the development of a 150-m-deep quarry according to the technological schemes of HMS, CFT, and MCSP are shown in Figure 4.

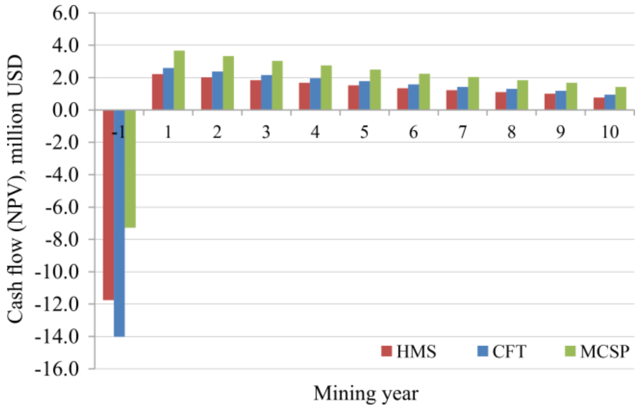

Figure 4. Dependence of the discounted cash flow indicator from the year of quarry development with a depth of 150 m

Analysis of the obtained dependencies (Fig. 4) confirms that at a quarry depth of 150 m, the most effective discounted cash flow is the technological scheme of the MCSP. This is achieved because its costs are minimal at the preparatory stage of quarry development, and operating costs during the project implementation are the lowest.

It was also established that according to the considered technological schemes, the lowest discounted cash flow for 10 years is when using the HMS scheme. However, this scheme is more attractive at the preparatory stage than the CFT scheme.

The established dependencies show that when the quarry depth is increased to 150 m, the discounted cash flow value for the HMS technological scheme is 3.0 million USD, which is 3.6 times less than with a quarry depth of 100 m. Using the CFT scheme allows for an insignificant increase in this indicator to 3.3 million USD, which is 3.8 times less than at a quarry depth of 100 m. The best indicator is the MCSP scheme, where the total discounted cash flow value reaches 17.2 million USD, only 15% less than a quarry depth of 100 m.

The obtained intermediate results state that the total cash flow under the MCSP scheme is 5.8 times better than that of the HMS scheme and 5.2 times better than the CFT scheme. Thus, a 1.5-fold increase in quarry depth from 100 to 150 m leads to a significant decrease in the total value of NPV cash flow in the HMS and CFT schemes, associated with high capital and operating costs when developing quarries at substantial depths.

The results of the indicators obtained of the NPV cash flow value by the years of enterprise operation allow the evaluation of the technological schemes of HMS, CFT, and MCSP to proceed according to the indicator of the project investments' payback period.

3.2. Establishing the company cash balance (NPV) during quarry exploitation

When determining the investment payback period, a technique was used to determine the company's cash balance (NPV) indicators over the years, which allows for choosing the most attractive technological scheme for the development of a quarry at the same depths of working out the deposit and productivity indicators of the quarry.

Comparison of technological schemes according to the indicator of discounted cash flow is an effective tool when evaluating long-term projects. Also, the indicators of cash flow over the years allow for comparing technological schemes by the payback period of investments, which is more in demand when attracting credit money.

During the analysis of the development effectiveness of the quarry with given productivity when applying technological schemes of HMS, CFT, and MCSP, the development depth of 50 m was primarily considered. According to the results of establishing indicators of the company's cash balances considering the time factor, each scheme in the first year of quarry development has a negative balance. This is due to high capital costs in the preparatory period; however, for each scheme, the 3-year project is the payback period. To establish a more accurate investment payback period, consider the impact of time on the company's cash balance (Fig. 5).

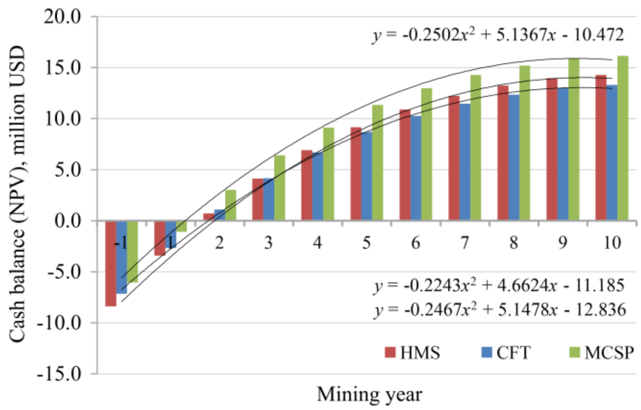

Figure 5. Dependence of the investment payback period on the year of quarry development at a depth of 50 m

Dependencies established in (Fig. 5) allow us to determine that according to the indicator of the payback period at a quarry depth of 50 m, the most effective is the technological scheme of the MCSP. When applied, the payback period is 2.2 years of project implementation, 25% less than the HMS scheme and 19% less than the CFT scheme. It is also worth noting that at a given quarry depth, the use of the TCT technological scheme is more attractive in terms of the payback period (by 4%) compared to the HMS scheme. However, according to the enterprise cash balance (NPV) indicator, the HMS scheme is 7%.

As can be seen from the graphs (Fig. 5), in the 3rd year of career development, the company's cash balance at the HMS scheme reaches the indicators of the CFT scheme and subsequently exceeds them. Thus, the preference in choosing the HMS scheme over the CFT will be determined depending on the priority of investment payback period indicators or the size of the company's cash balance at the end of the project implementation.

Next for comparison are the indicators of the company cash balance and the investment payback period for technological schemes of HMS, CFT, and MCSP when working out a quarry with a depth of 100 m. When determining the indicators of discounted cash flow, the most attractive scheme during the 11 years of project implementation was MCSP, whereas the HMS scheme had the worst performance. When using this scheme, the total cash flow cost was lower by 1.8 and 1.14 times compared to the schemes of MCSP and HMS, respectively. To evaluate the efficiency of the considered schemes, the cash balance of the enterprise was determined by the indicator of the investment payback period during 11 years of project implementation at a quarry development depth of 100 m.

Dependencies of the discounted cash flow of the enterprise on the project implementation term at the quarry depth of 100 m are shown in (Fig. 6). The analysis of the received indicators of the company's cash balances by year confirms the significant impact of increasing the quarry depth to 100 m on the efficiency of the technological schemes of HMS and CFT. The investment payback period rises from two to three years of project implementation, while when applying the MCSP scheme, the company's cash balance decreases by only 11% compared to the development of a 50 m deep quarry.

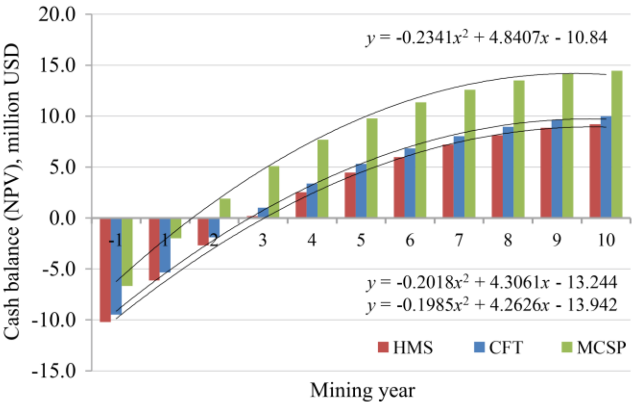

Figure 6. Dependence of the investment payback period on the year of quarry development at a depth of 100 m

According to the established dependencies (Fig. 6), the investment payback period according to the technological scheme of the MCSP is 2.5 years, which is 44% less than when using the CFT scheme (3.6 years) and 57% less than when using HMS (3.9 years). This additionally confirms the decrease in the effectiveness of the HMS and CFT schemes when the quarry depth increases from 50 to 100 m compared to the indicators of the MCSP scheme.

In contrast to the indicators of technological schemes HMS and CFT that were recorded when developing a quarry with a depth of 50 m, increasing the depth to 100 m leads to the fact that, according to the CFT scheme, the payback period decreases by 8%, and the cash balance of the enterprise increases by 9% at the end of the project implementation in comparison with the HMS scheme. Thus, the use of HMS technology is the least attractive compared to the schemes of CFT and MCSP at a quarry depth of 100 m, both in terms of the payback period and the discounted cash balance of the enterprise during the 11 years of project implementation.

The last stage of research comparing the effectiveness of the technological schemes HMS, CFT, and MCSP in terms of the investment payback period is establishing enterprise discounted cash balances at the quarry depth of 150 m. When analyzing the relevant parameters at a quarry depth of 50-100 m, it was found that the most effective technological scheme is MCSP. The CFT scheme is ahead of the HMS scheme in terms of efficiency at a development depth of 100 m, and at a quarry depth of 50 m, it has approximately the same indicators.

To evaluate the efficiency of HMS, TPT and MCSP schemes and to determine the most attractive in terms of the investment payback period, the distribution of cash balances by year during the development of a 150-m-deep quarry was established (Fig. 7). According to the obtained indicators of cash flow, it can be stated that when applying the technological schemes HMS and CFT in quarries with a depth of 150 m, the financial indicators of the enterprise deteriorate significantly in comparison with the scheme MCSP. As can be seen from the given data, the company cash balance for the 11th year of project implementation will be the smallest under the HMS scheme and amount to 4.6 million USD, 16% less than under the CFT scheme and 2.7 times less than under the MCSP.

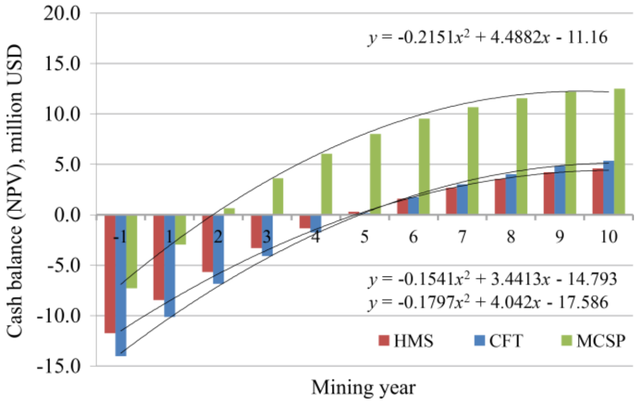

Figure 7. Dependence of the investment payback period on the year of quarry development at a depth of 150 m

When determining the investment payback period (Fig. 7) at the developing quarry with a depth of 150 m, a clear advantage of the technological scheme of the MCSP was established. In this case, the investment payback period is 2.8 years, only 12% more than when developing a quarry with a depth of 100 m. At the same time, when using HMS and CFT technological schemes, the investment payback period will increase to 5.8 and 5.9 years, respectively. The specified payback periods are pretty long and may be perceived by investors as unacceptable in some instances, making it impossible to use these schemes in practice at the quarry depth of 150 m.

In the general comparison of the technological scheme MCSP with others regarding the investment payback period, it is 2.0 times less than when using the HMS scheme (5.8 years) and 2.1 times less than when using CFT (2.9 years). It is also worth noting that a similar situation occurs at a quarry depth of 150 m, recorded at a quarry development depth of 50 m. The advantage of choosing between technological schemes, such as HMS and CFT, will be determined depending on the priority of the payback period indicators or the cash balance of the enterprise.

At this depth, the application of the HMS technological scheme is more attractive in terms of the payback period (by 2%) compared to the CFT scheme; however, according to the indicator of the company cash balance (NPV) at the end of the project implementation, the CFT scheme is 16% more effective than the TCR due to accumulation more profit. In this case, in the 5th year of quarry development, the company cash balance under the CFT scheme exceeds the HMS scheme's indicators.

3.3. Determining the effectiveness of technological schemes by indicators of cash flow value and profit (NPV)

Established dependences of discounted cash flow and cash balance of the enterprise on the development year allow for determining the quarry depth's influence on each technological scheme's investment attractiveness. First, consider the dependence of the total cash flow indicator (NPV) value on the quarry depth at developing construction raw materials deposit at a given productivity of 1.6 million m^3 (Fig. 8).

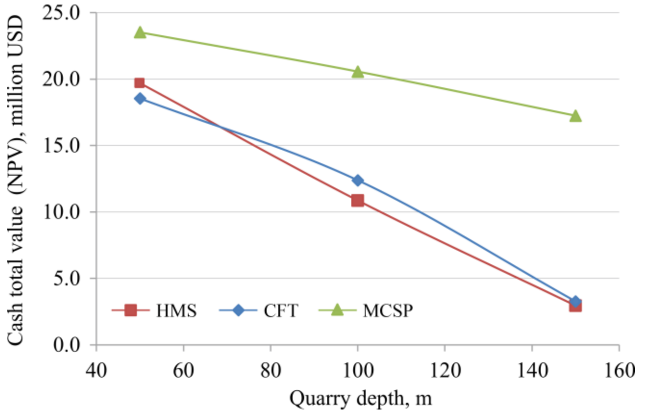

Figure 8. Dependence of the NPV cash flow total value on the quarry depth for 11 years of project implementation at the enterprise productivity of 1.6 million m^3 of crushed stone per year

According to the obtained dependencies (Fig. 8), the technological scheme of the MCSP is more attractive than others during the 11 years of implementation in the quarry depth range of 50-150 m. Its most excellent efficiency in terms of the total value of the cash flow indicator is achieved at a quarry depth of 50 m and is 23.5 million USD. When the quarry depth is increased three times to 150 m, the effectiveness of the MCSP scheme decreases by 1.36 times and reaches 17.2 million USD.

It is worth noting that according to the indicator of the cash flow total cost NPV, technological schemes HMS and CFT are incredibly close in efficiency when increasing the quarry depth from 50 to 150 m. An increase in the quarry depth in the specified range for these schemes decreases their efficiency by 5.6 and 6.6 times for CFT and HMS schemes, respectively. This confirms the significant advantage of the MCSP scheme since its use does not result in such a substantial reduction in the total cash flow value.

According to the graphs (Fig. 8), when comparing the HMS and CFT schemes for quarry depths of 50 m, the first scheme is more effective since its indicator of the cash flow total cost will be 6% higher than under the CFT scheme. However, when the depth of the quarry increases to 100 m according to the CFT scheme, the cash flow value will be 12.4 million USD, which is 14% higher than under the HMS scheme (10.9 million USD). When the quarry depth increases to 150 m, the efficiency of the CFT scheme will be 10% higher than that of the HMS, with a total cash flow cost of 3.0 million USD.

The conducted studies on establishing cash flow during the project implementation made it possible to determine the influence of the quarry development depth on the enterprise profit when applying the technological schemes HMS, CFT, and MCSP. The indicators of the total discounted profit of the enterprise for 11 years of project implementation were determined, taking into account the depth of the quarry and its productivity of 1.6 million m^3/year, shown in Figure 9.

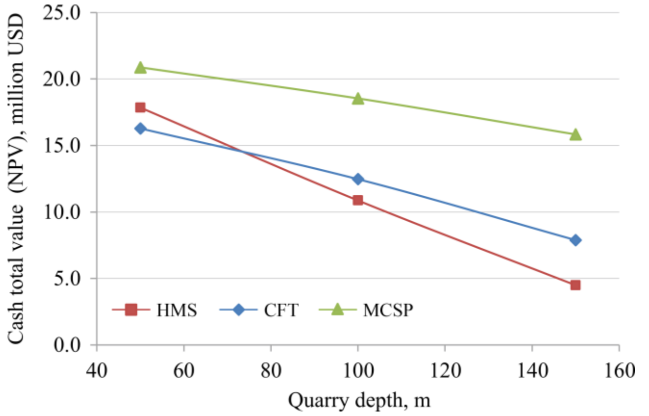

Figure 9. The impact of the quarry depth on the total profit of the enterprise NPV for 11 years of project implementation

Determining the total profit enterprise dependence on the quarry depth using technological schemes HMS, CFT, and MCSP (Fig. 9) allows claiming that the scheme of MCSP is the best according to this indicator in the specified range of deposit development depths. The maximum profit NPV is achieved according to this scheme when developing a quarry with a depth of 50 m and is 20.9 million USD. When the quarry depth is increased to 150 m, the total profit under this scheme decreases by 1.31 times and is 15.8 million USD.

In contrast to the indicator of the total cost of cash flow, technological schemes such as HMS and CFT have clear efficiency limits according to the indicator of total profit. When developing a quarry with a depth of 50 m, the efficiency of the HMS scheme will be 9% higher than the CFT scheme and will be 17.8 million USD. During the increase of the quarry depth to 72 m, the technological scheme of the CFT will have a similar total NPV profit with the HMS scheme, which will be 14.5 million USD. With further growth of the quarry depth, the efficiency of the CFT scheme in terms of total profit will increase and reach 7.9 million USD at a development depth of 150 m, which is 75% higher than under the HMS scheme.

When comparing the schemes HMS and CFT with MCSP, it was found that at a quarry development depth of 50 m, the difference between them is 17 and 28%, respectively. This is due to the relatively small difference in capital and operating costs for these schemes at small quarry development depths.

When the quarry depth increases to 150 m, the technological scheme of the MCSP has significant advantages compared to the HMS and CFT schemes. When applying the MCSP scheme instead of HMS, with the indicated mining depth, the total profit of the enterprise will increase by 3.5 times from 4.5 to 15.8 million USD for 11 years of project implementation, which confirms the high efficiency of the proposed solutions. During the comparison of the company's total profits, the NPV of the technological schemes of the MCSP and CFT established the advantage of the first in 2.0 times, which allows for increasing the profit during the implementation of the project by 7.9 million USD.

3.4. Comparison of the technological schemes according to the investment payback period indicator

The obtained research results allow the establishment of the influence of the quarry depth development on the payback period of investments, taking into account the technical and economic indicators of the implementation of HMS, CFT, and MCSP technological schemes. Since comparing the technological schemes' efficiency according to the investment payback period indicator is one of the most recognized evaluation methods in decision-making, the previous results can only serve as supporting material. The established dependences of the investment payback period on the quarry depth according to three technological schemes are shown in Figure 10.

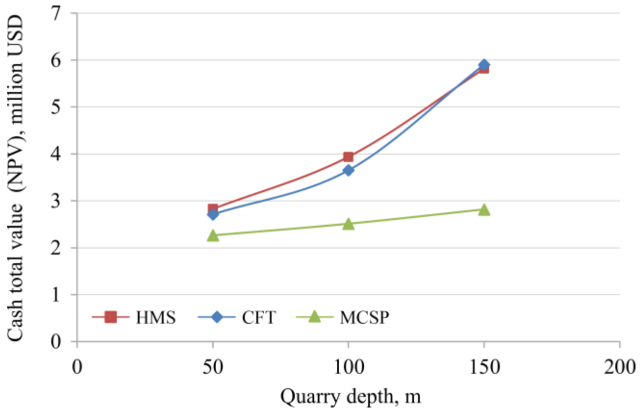

Figure 10. Dependence of the investment payback period on the quarry depth mining at the yearly productivity of 1.6 million m^3 of aggregates

The determined impact of quarry depth on the investment payback period (Fig. 10) when comparing three technological schemes, HMS, CFT, and MCSP, allows us to claim that the last scheme is the most effective in the range of quarry depth 50-150 m. Due to the reduction of capital and operating costs compared to the HMS and CFT schemes, the minimum investment payback period is 2.3 years at a quarry depth of 50 m. Further increase of the quarry depth to 150 m when using the MCSP scheme leads to an increase in the investment payback period by 24% to 2.8 years.

A comparison of the technological scheme MCSP with the schemes HMS and CFT states that with a quarry depth of 50 m, the payback period of the former decreases by 19 and 24%, respectively. When the depth of the quarry is further increased to 150 m, the effectiveness of the MCSP scheme rises due to the insignificant influence of the quarry depth on the payback period. Compared with the HMS scheme, the payback period of the MCSP scheme at a quarry depth of 150 m is reduced by 2.09 times, while the effectiveness of the CFT scheme is lower by 2.06 times.

The HMS and CFT technological schemes have similar indicators of the investment payback period when the quarry depth increases from 50 to 150 m. At a quarry depth of 50 m, the CFT scheme is more effective, with a payback period of 2.7 years, 4% less than the CFT scheme. When the quarry depth is increased to 140 m, the payback period for the CFT technological scheme is equal to the payback period of the HMS scheme, which is 5.2 years. With the further increase of the quarry depth to 150m, the HMS technological scheme becomes more effective than the CFT scheme by 2%, while the investment payback period is 5.8 years.

It is worth noting that in the case of deciding the impracticality of investments with a maximum payback period of more than 5 years, technological schemes HMS and CFT can be applied only when the quarry depth of the specified productive capacity is up to 134 m. Further increase of the depth under these schemes will lead to the absence of the necessary profit and unsatisfactory terms of investment payback, which are required to implement the project.

4. Conclusions

The influence of the quarry depth on the cash flow discounted value indicators, the net income of the enterprise NPV, and the investment payback period when using the HMS, CFT, and MCSP schemes was established, which made it possible to prove the effectiveness of the last technological scheme at the given productivity of the quarry 1.6 million m^3/year.

According to the total discounted cash flow value indicator, the technological scheme MCSP is the most attractive at the quarry depth range of 50-150 m. According to this indicator, the efficiency of the MCSP scheme is better compared to the HMS and CFT schemes by 19 and 26%, respectively, at a quarry depth of 50 m. When the quarry depth increases from 100 to 150 m, the effectiveness of the MCSP scheme in terms of the total cash flow indicator will be 5.2 and 5.8 times exceeding the indicators of the CFT and HMS schemes, respectively.

The influence of the quarry depth on the indicator of the total cash flow cost when applying the considered schemes was established. It was determined that the use of the MCSP scheme in comparison with the HMS and CFT schemes at a quarry depth of 50 m is more effective by 17 and 28%, respectively. At the same time, with a quarry depth of 150 m, the efficiency of the MCSP's technological scheme in terms of the enterprise's overall profit increases significantly. It is 2.0 and 3.5 times superior to the CFT and HMS schemes.

The influence of the quarry depth on the investment payback period was determined, confirming the superiority of the technological scheme MCSP over other schemes for quarry depths of 50-150 m. It was established that for a quarry depth of 50 m, the investment payback period for the MCSP scheme is shorter by 19 and 24%, compared to HMS and CFT schemes, respectively. When the quarry depth is increased to 150 m, the effectiveness of the MCSP scheme rises even more, making it possible to reduce the investment payback period by 2.06 and 2.09 times compared to the CFT and HMS schemes, respectively.

It was established that with limited investment payback periods of up to 5 years, using HMS and CFT technological schemes is possible only at a maximum depth of 134 m. Further increase in depth will lead to the absence of the necessary profit that guarantees the given investment payback period.

Author contributions

Conceptualization: BS; Data curation: BS, VK; Formal analysis: OL; Funding acquisition: VK; Investigation: OL, VK; Methodology: OL, VK; Project administration: BS; Resources: VK; Software: OL; Supervision: BS; Validation: OL, VK; Visualization: OL; Writing – original draft: BS, OL, VK; Writing – review & editing: BS, OL. All authors have read and agreed to the published version of the manuscript.

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Conflicts of interests

The authors declare no conflict of interest.

Data availability statement

The original contributions presented in the study are included in the article, further inquiries can be directed to the corresponding author.

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Оцінка інвестиційної привабливості використання мобільної дробильно-сортувальної установки при розробці нерудних кар'єрів

Б. Собко, О. Ложніков, В. Крячек

Мета. Встановити вплив глибини розробки родовища нерудних матеріалів на термін окупності інвестицій при застосуванні транспортної системи розробки (ТСР), циклічно-потокової технології (ЦПТ) та мобільної дробильно-сортувальної установки (МДСУ) із порівнянням їх ефективності.

Методика. При виконанні досліджень використовувалися методики визначення дисконтованої вартості грошових потоків, прибутку підприємства NPV і терміну окупності інвестицій. Під час встановлення техніко-економічних показників роботи гірничого підприємства враховано фактор теперішньої вартості майбутніх витрат і прибутків.

Результати. Відповідно до показника загальної дисконтованої вартості грошових потоків технологічна схема з використанням мобільної дробильно-сортувальної установки є найбільш привабливою в діапазоні глибини кар'єру 50-150 м. Встановлено, що за даним показником вона є кращою у порівнянні зі схемами транспортної системи розробки і циклічно-потоковою технологією відповідно на 19 і 26% при глибині кар'єру 50 м. При зростанні глибини кар'єру зі 100 до 150 м ефективність схеми МДСУ за показником загальних грошових потоків буде у 5.2 і 5.8 разів перевершувати показники схем ЦПТ і ТСР, відповідно.

Наукова новизна. Встановлено вплив глибини розробки родовища на показники дисконтованої вартості грошових потоків, чистого доходу підприємства NPV і терміну окупності інвестицій, що дозволило визначити найбільш ефективну технологічну схему при заданій продуктивності кар'єру 1.6 млн $м^3$/рік. Визначено, що використання схеми з мобільною дробильно-сортувальною установкою у порівнянні зі іншими схемами за показником загальної вартості грошових потоків є більш ефективним на 17-28% при глибині розробки кар'єру 50 м. У той же час при глибині кар'єру 150 м, ефективність технологічної схеми МДСУ за показником загального прибутку підприємства суттєво зростає, і у 2.0 та 3.5 разів перевершує схеми ЦПТ і ТСР, відповідно.

Практична значимість. Виконані дослідження є важливими при виборі технологічних схем експлуатації кар'єрів нерудної сировини при зростанні їх глибини розробки. Особливо це актуально для гірничих підприємств, що займаються виробництвом щебню, де мобільні дробильно-сортувальні установки можуть забезпечити значне підвищення економічної ефективності.

Ключові слова: *кар'єр, розробка нерудних родовищ, циклічно-потокова технологія, мобільна дробарка, термін окупності інвестицій*

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