Optimization of capacity and the number of crushing and transfer stations at the deep open pits

Yuriy Vilkul

D.Sc. in engineering, professor
Open-cast Mining Department
Kryvyi Rih National University
Kryvyi Rih, Ukraine

Valeriy Slobodyanyuk

PhD, Associate Professor
Open-cast Mining Department
Kryvyi Rih National University
Kryvyi Rih, Ukraine
E-mail: slobod_v@i.ua

Ivan Maximov

PhD, Associate Professor
Mathematics Department
Kryvyi Rih National University
Kryvyi Rih, Ukraine
E-mail: ktu@alba.dp.ua

Abstract
Dependence of the technical and economic performance of truck haulage on the number and location of transfer stations in the working area of the pit was investigated. Analytical dependence to determine the optimum number of transfer stations when they are uniformly distributed along the length and depth of the working area was specified. The special features of change in key performance of mining motor transport depending on the number of crushing and transfer stations in the CCPF technology, pit capacity and size of the working area were detected. The conditions for simultaneous use of multiple crushing and transfer stations, their major process parameters and the optimum number of stations located horizontally and vertically were determined, the economic efficiency of process

flowcharts with multiple transfer stations was estimated. The investigations made have shown that in all cases, optimization and increase in the number of transfer stations leads to a decrease in the number of dump trucks by 50-60% compared to the option of using one transfer station. Increasing the number of transfer stations, while reducing the number of dump trucks, improves reliability of truck haulage. Optimizing the number of transfer stations reduces the required capacity of each crushing and transfer equipment to 10-20 million tons/year. The use of mobile crushing and transfer stations neither freezes ore reserves, nor impedes the development of the working area.

Keywords: CYCLIC AND CONTINUOUS PRODUCTION FLOW TECHNOLOGY, HAULAGE LEVEL, CRUSHING AND TRANSFER STATION

The problem and its relation to the scientific and practical tasks

An effective way to stabilize and reduce the operating costs for open cast mining the iron ore deposits is the reconstruction of a transport flowchart at the open pit. Implementation of this solution requires significant capital costs. The requirements, which the transport system of a deep open pit should meet, have been set in the world practice of opencast mining operations [1]. Along with the equipment reliability, this is a transport capability to adapt to the ever-changing mining conditions in the best possible way. At the same time, when designing the Ukrainian iron ore pits, the solutions implemented in the CCPF technology during the 70s to 80s of the last century are still prevalent. The basis for these solutions is the use of stationary crushing and transfer stations at the open pits. The progress deepening of Krivbass iron ore pits and the required increase in rock haulage from the stope to the CCPF transfer stations reduce the economic efficiency of opencast mining operations. The evaluation of expedience and conditions of the simultaneous use of multiple crushing and transfer stations has not been adequately reflected in the mining theory.

Analysis of the recent researches and publications

At the Ukrainian iron ore open pits, rock transportation is mostly provided via the cyclic continuous production flow technology [2-8]. The flowcharts of relatively simple topology with one stationary crushing and transfer station are generally used. This reduces the costs for raising the rock to the surface, but the costs for rock haulage to the transfer stations remain significant. These costs increase as the open pit deepens and the working area expends. The issues of feasibility of relocating a transfer station with deepening the mining operations have been investigated in the opencast mining theory, but the issues of simultaneous use of multiple crushing and transfer stations are under-investigated.

The authors previously investigated the issue of simultaneous use of multiple transfer stations [9], which were located within one haulage level. The problem of determining the optimum number of transfer stations and the key process parameters have been solved. It is shown that three transfer stations may be efficiently used for a wide range of the pit capacity (10-40 mln. t/year). A further increase in the number of crushing and transfer stations does not result in a significant improvement of technical and economic performance. In the paper [10], the authors developed a method of determining the optimal number of transfer stations located both vertically and horizontally at a deep open pit.

Statement of the research problems

The aim of this work is to investigate the dependence of technical and economic performance of truck haulage on the number and location of transfer stations in the working area of the open pit.

The following problems were solved during the work:

- determination of analytical dependence in order to know the optimum number of transfer stations when they are uniformly distributed along the length and height of the working area;
- investigation of special features of change in key performance of mining motor transport depending on the number of crushing and transfer stations in the CCPF technology, pit capacity and size of the working area.

The material presentation and results

The key provisions of methods for determining the optimum number of transfer stations are discussed in the work [10]. Therewith, the major objective are to reduce the total costs for delivering the rock to the main conveyor.

$$Z = 0,001Q\left(C_A + \frac{A}{q \cdot T_A}\right)\left(\frac{l}{4n} + \frac{H}{4mi}\right) + 0,001C_k Qkd + \frac{C_0}{T_K} mnkd + \frac{C_Д}{T_Д} mn, \qquad (1)$$

where C_A is the cost of rock haulage by truck, UAH/tkm; A is the cost of one dump truck, UAH; q is an annual capacity of a dump truck, tkm/year; T_A is the rated service life of a dump truck, years; C_0 is the capital costs per running meter of additional conveyor ways (takes into account the costs for tunneling and construction of the conveyor), UAH/m; T_K is a life span of auxiliary conveyor ways, years; C_K is the cost of conveying the rock, UAH/tkm; T_D is a life span of a crushing and transfer station, years; C_D is the capital costs for one crushing and transfer station, UAH.

The optimum number of transfer stations located vertically and horizontally with the minimized costs were determined.

$$n_0 = l \times \sqrt[3]{\frac{0,001\left(C_A + \frac{A}{q \cdot T_A}\right) \times i}{4\left(\frac{C_0}{T_K} kd + \frac{C_Д}{T_Д}\right)} \times \frac{Q}{Hl}}; \qquad (2)$$

$$m_0 = \frac{H}{i} \times \sqrt[3]{\frac{0,001\left(C_A + \frac{A}{q \cdot T_A}\right) \times i}{\left(\frac{C_0}{T_K} kd + \frac{C_Д}{T_Д}\right)} \times \frac{Q}{Hl}} \qquad (3)$$

The total number of transfer stations is

$$m_0 n_0 = \sqrt[3]{\left(\frac{0,001Q\left(C_A + \frac{A}{q \cdot T_A}\right)}{\frac{C_0}{T_K} + \frac{C_Д}{T_Д}}\right)^2 \frac{lH}{16(kd)^2 i}}. \qquad (4)$$

The factors under the cube roots in formulas (2), (3) are the same and define some proportionality factor for the values m_0 and n_0. The optimum number of transfer stations located horizontally is proportional to the length of the mining area, and that located vertically is proportional to the height of the area and inversely proportional to the road slope. Since the price and mining and geometrical parameters in formulas (2) and (3) are under the cube roots, even the significant changes in one of them result in a slight change in the optimum number of transfer stations. If any of parameters or above fractions changes by 30%, n_0 and m_0 change by 9% only. Even if one of input parameters, e.g. the capacity, changes twice, the optimum values n_0 and m_0 change by 26%.

In terms of above mentioned formulas and dependence obtained, an economic and mathematical model was constructed. The optimum number of transfer stations located horizontally and vertically, their total number, dimensions and area of separate zones, the capacity of one crushing station, the number of dump trucks required, the total economic impact of optimizing the truck and conveyor transport were determined using this model. The development of mining operations at the open pits with the working area between 100m and 600m in depth and 1000 m and 6000m in length was simulated.

If the working area and a pit capacity are of small size, the use of one transfer station is the best choice (for example, at H=100m, L=1000m and pit capacity less than 25 mln t/year). In all other cases, the optimum number of crushing stations is increased from 2 to 8. Therewith, both the depth and the length of the working area equally effect on an increase in the number of transfer stations, which also follows from formula (4), where L and H effect to the same extent. It is found that at least two transfer stations would be efficiently used if the pit depth exceeds 200m or the length of the working area is over 2000m.

The optimum number of transfer stations to be determined is an integer (a round figure) with an integer of haulage levels and transfer stations on each level. Therefore, with H=200m and L=4000m, two haulage levels by two transfer stations (4 in total) were determined, and when increasing the length of the working area up to 5000-6000 m, one haulage level with three transfer stations was determined as the best (a disproportional increase in the number of transfer stations with deepening and lengthening the working area is explained in a similar way).

As seen from Table 1, the use of 2 to 6 transfer stations for the pit capacity of 25 mln t/year is always efficient and provides a significant reduction in transport costs. The analysis of Table 2 shows that in most cases, the use of multiple transfer stations even at the pit of 10 mln t/year capacity is reasonable. Using one transfer station is feasible at a shallow depth and short length of the working area.

Table 1. The optimum number of transfer stations for different depths and widths of the working area with an annual pit capacity of 25 mln t

Height of the working area, m	Length of the working area, m					
	1000	2000	3000	4000	5000	6000
100	2	2	3	3	4	4
200	2	4	4	4	3	3
300	3	2	4	4	4	6
400	4	3	6	4	4	6
500	4	3	3	6	6	4
600	5	4	3	6	6	6

Table 2. The optimum number of transfer stations for different depths and widths of the working area with an annual pit capacity of 10 mln t

Height of the working area, m	Length of the working area, m					
	1000	2000	3000	4000	5000	6000
100	1	1	2	2	3	3
200	2	1	1	2	2	2
300	2	2	2	2	2	2
400	3	2	2	2	4	4
500	3	3	2	2	4	4
600	3	3	3	2	2	4

The main target of the intermodal mining transport is to minimize the costs for the collecting transport, which operates at the pit stopes. The investigations made have shown that in all cases, optimization and increase in the number of transfer stations lead to a decrease in the number of dump trucks by 50-60% (by 2-2.5 times) compared to the option of using one transfer station, wherein this decrease is observed in all options on the same level. Increasing the number of transfer stations, while reducing the number of dump trucks, improves reliability of truck haulage, slackens the traffic density at the pit and shortens the unproductive time while waiting at the transfer stations.

Optimizing the number of transfer stations makes it possible to significantly reduce the capacity of each crushing and transfer station. Having the small size of the working area and one or two transfer stations, the capacities are 25-30 mln t/year. With deepening the working area up to 300 m and lengthening up to 3000 m, the optimum number of transfer stations increases, and their capacities fall to 15-20 mln t/year. With further increase in size of the working area the capacities of crushing and transfer stations drop to 7-10 mln t/year. Reducing the required capacity of transfer stations enables to equip them with the primary jaw crushers of low weight and low costs for relocation and maintenance. The use of mobile crushing and transfer stations in the CCPF technology neither freezes the significant ore reserves for decades, nor impedes the development of the working area.

The economic efficiency ($\Delta Z = Z_1 - Zm_0n_0$), being equal to the difference between the total costs for delivering the rock to the main conveyor at one crusher (Z_1) and at the optimum number (Zm_0n_0) of crushers, was used as a criterion of the process flowchart optimization. At the pit capacity of 25 mln. t/year, the use of the optimum number of crushing and transfer stations reduces the costs for mining transport by 15-25% at a 200-300m depth and 2000-3000m length of the working area, and by 25-40% at the large-sized working area. At the pit capacity of 10 mln. t/year, the cost reduction by 10-17% is observed at a 300-400m depth and 3000-4000m length of the working zone. By increasing the pit capacity up to 40 mln. t/year, the reduction in costs for mining transport is 25-30% at a 200-300m depth and 2000-3000m length of the working area, and runs up to 40-50% at the large-sized working area.

Let us consider the nature of change in the number of dump trucks when optimizing the CCPF parameters at the pit capacity of 25 mln t/year at a 400m depth of the working area with changing its length from 1500 to 4500m (Fig.1).

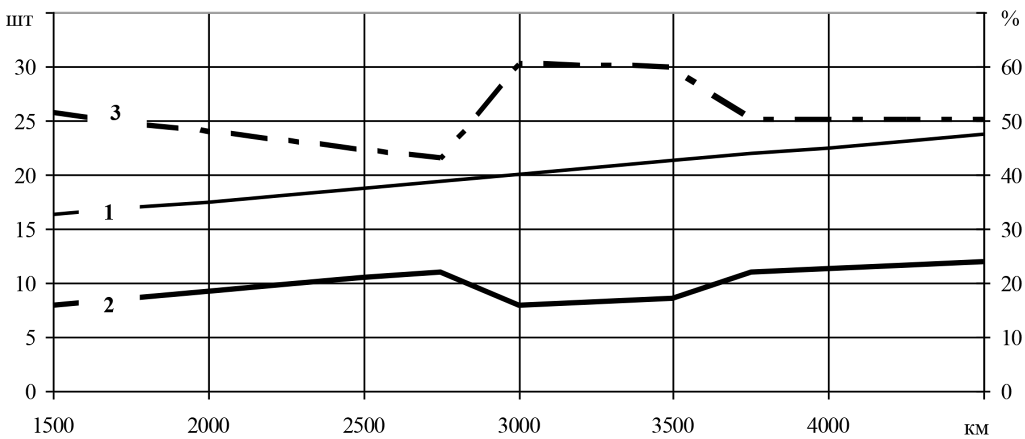

Figure 1. Change in the number of dump trucks at the different length of the working area (1 - with one crushing and transfer station, 2 - with the optimum number of crushing and transfer stations, 3 - a relative decrease in the number of dump trucks when optimizing the number of transfer stations,%)

The analysis of Fig.1 shows that at one transfer station with lengthening the working area the number of dump trucks increases from 16 to 24 on a pro rata basis. When optimizing the number of crushing and transfer stations (their number varies from 3 to 6) the number of dump trucks varies from 8 to 12. Thus, their percentage reduces by 50-60%. Due to the fact that the optimum number of crushing and transfer stations is rounded to an integer value, the change in their number horizontally and vertically is non-uniform, which explains the disproportion plotted in Fig.1. In the above case, the required capacity of one crushing and reloading station varies from 4.2 mln t/year to 8.2 mln t/year.

When designing the procedure of open pit development with a high capacity on the stage of prefeasibility study, it is necessary to determine the optimum number of transfer stations and the diagram of relocation thereof as the mining operations progress. This can significantly reduce the total costs for mining transport, decrease the number of dump trucks and improve the operating environment. Using the movable crushing and transfer stations makes it possible to improve the mining operations and does not require retaining the pillars of accessed ore reserves under the transport facilities.

Conclusions and trends for further researches

The researches have shown the ability to significantly reduce the costs for truck and conveyor transport using the optimum number of multiple movable crushing and transfer stations. The research results may be used in reconstruction of CCPF technology at the deep open pits. The further researches require substantiating the construction of a movable crushing and transfer station and the methods of mining operations to use simultaneously in the working area.

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