REARRANGEMENT METHODOLOGY OF THE OPEN PITS GROUP PERFORMANCE AS A PART OF THE MINING AND PROCESSING PLANT

Serhii Joukov[1], Serhii Lutsenko[1], Volodymyr Peregudov[2], Ihor Hryhoriev[2]*
[1] Kryvyi Rih National University, Kryvyi Rih, Ukraine
[2] SDI "Krivbassproekt", Kriviy Rih, Ukraine
**Corresponding author: lutsenkoserhii@knu.edu.ua*

Abstract. Productivity must be managed both at the level of a separate open pit and a group of open pit mines in order to maximize profit. At the same time, the productivity of each open pit that is part of the mining and processing plant should be determined based on the highest efficiency of the mining and processing plant.

A method has been developed for rearrangement of the productivity of the open pits group that are part of a mining and processing plant, which takes into account the relationship between the mining mode and ore productivity when the demand for iron ore products changes. Current methodology allows to adjust mining operations to different market terms and, contrary to existing methodologies, this one includes interrelation between mining operation mode and ore extraction productivity.

It has been proven that the best option for the ore performance of open pits when planning the development of mining operations at Northern MPP is the option when the Pervomaysky open pit works with the maximum possible productivity, and the Annovsky open pit provides a capacity of 9 million tons/year.

Key words: open-cast mining; mines goup; open pits productivity for ore mining, mining operations mode, mining operations development strategy.

МЕТОДИКА ПЕРЕРОЗПОДІЛУ ПРОДУКТИВНОСТІ ГРУПИ КАР'ЄРІВ, ЩО ВХОДЯТЬ ДО СКЛАДУ ГІРНИЧО-ЗБАГАЧУВАЛЬНОГО КОМБІНАТУ

С.А.Жуков[1], С.А.Луценко[1], В.В.Перегудов[2], І.Є.Григор'єв[2]*
[1] Криворізький національний університет, Кривий Ріг, Україна
[2] ДП«ДПІ«Кривбаспроект», Кривий Ріг, Україна
**Відповідальний автор: lutsenkoserhii@knu.edu.ua*

Анотація. Продуктивністю необхідно керувати, як на рівні окремого кар'єра, так і групи кар'єрів комбінату з метою отримання максимального прибутку. При цьому продуктивність кожного кар'єру, що входить до складу гірничо-збагачувального комбінату слід визначати виходячи з найбільшої ефективності роботи ГЗК.

Розроблено методику перерозподілу продуктивності групи кар'єрів, що входять до складу гірничо-збагачувального комбінату, яка враховує взаємозв'язок режиму гірничих робіт і продуктивності по руді при зміні потреби в залізорудній продукції. Запропонована методика дозволяє адаптувати гірничі виробництва, до мінливих умов ринку і при цьому, на відміну від існуючих методик враховує взаємозв'язок режиму гірничих робіт і продуктивності кар'єру по руді.

Доведено, що найкращим варіантом продуктивності кар'єрів по руді при плануванні розвитку гірничих робіт Північного ГЗК є варіант, коли Першотравневий кар'єр працює з максимально можливою продуктивністю, а Ганнівський кар'єр забезпечує продуктивність 9 млн. т/рік.

Ключові слова: відкриті гірничі роботи, група кар'єрів, продуктивність кар'єрів по руді, режим гірничих робіт, стратегія розвитку гірничих робіт.

1. Introduction.

One of the most important tasks of the open pit design is to make technical decisions that ensure stable, uninterrupted operation of the open pit and the mining and processing plant as a whole for the minerals extraction of a given quality and with minimal costs [1]. Modern approaches to the open pit design are based on the assumption that the parameters of the external and internal environment will be relatively constant, and therefore, no significant changes in the design and parameters of the mining system in the long run are provided. Therefore, a stable calendar schedule for a sufficiently long period of development, laying the investments at a fundamental level, that contribute to the long-term development of the work area, was always aimed to be adopted while the design. The practice of open pits work shows that in times of crisis there is a sharp decline in the scope of overburden works. This decline reflects the desire of enterprises to limit the growth of production costs through the formation of temporarily non-operating open pit sides, as well as working boards with increased angles. This is largely due to the inability of mining companies to provide flexible reaction to changes in domestic and external demand for products without a significant increase in development costs, as the designs of the open pit development do not provide for changes in the intensity of the open pit development over long periods.

Besides, there is no mechanism for a reasonable choice of production capacity of the open pit and the mode of mining operations, taking into account their relationship [2, 3], when the need for iron ore changes [4]. Thus, an increase in the demand for minerals, in most cases, leads to an increase in production, and the coefficients of overburden was not changed, a decrease in demand – leads to a decrease in mining, downtime of equipment, buildings and constructions, redundancy of workers, reduction of equipment time. In addition, to reduce the cost of marketable products, the overburden coefficients are reduced. The consequence of this is the presence of delays in overburden work at enterprises, the emergence of unscheduled temporary spoil banks, due to violation of the law of proportionate work and development of the open pit space, as well as the formation of temporary spoil banks in the production zone, which is unacceptable. Periodically there is a need to revise previous designs, due to the deviation of the actual state of mining from design decisions. Therefore, there is a need to adapt mining to changing market conditions. When operating open pits with constant production capacity, there are additional costs associated with the storage of unsold output in the warehouse - during a fall in demand, and companies miss the opportunity to increase profits during a period of growing demand due to the inability of immediately intensification of production to meet market needs. In this regard, the goals of domestic mining companies have changed. The issues of ensuring competitiveness, which depends on the adopted strategy of mining development, have become of paramount importance [5].

Under these conditions, the performance of the mining company must be adjusted in accordance with changing external conditions throughout its life [6]. That is, significantly increase the economic efficiency of development is possible through the implementation of flexible changes in extraction volumes with changes in demand for extracted products. Productivity must be managed both at the level of a separate open pit or a group of open pits of the plant, and at the level of a group of enterprises of one owner in order to obtain maximum profit. If the mining and processing plant includes several open pits, the productivity of each of them should be determined based on the highest efficiency of MPP.

2. Methodology.

Questions of improving the methods of determining the production capacity of the open pit are reflected in the works of many scientists: V.V. Rzhevsky [7], A.I. Arsentiev [8], B.P. Jumatov, M.G. Novozhilov, Shpansky O.V. [9], V.S. Hohriakov, V.G. Bliznyukov [10], N.V. Melnikov [11], K.J. Vinitskiy, E.I. Reentovich, V.A. Simkin. As a result of the analysis of scientific publications, it was found, that the existing scientific and methodological framework in the direction of design and planning of opencast mining does not provide for changes in the intensity of deposits development during long periods. This indicates the relevance of developing new and adjusting existing methods of planning the development of mining and determining the main parameters of the open pits, which

require reliable optimal design solutions. This does not take into account that the methods of determining the main parameters of the open pit, both one particular open pit and groups of open pits of the mining and processing plant, should be closely related to solving a set of problems, requiring a systematic approach to creating methods for determining optimal parameters and development indicators of these deposits.

Therefore, the goal was to develop a method of redistribution of production capacity of a group of open pits, that are part of the mining and processing plant when the need for iron ore products changes, which takes into account the relationship between mining and ore productivity, proceeding from a condition of maintenance of the standard of the ready for extraction reserves.

3. Results and discussion.

The greatest economic effect of the development of the raw material resource base of the plant can be obtained only when the productivity is not established for each open pit separately, but collectively for the group of the open pits, included in the system of the plant.

In order to regulate the intensity of development of the plant's deposits when the need for marketable products changes, it is necessary, for the first time, to determine the maximum productivity of the mining opportunities of each open pit [12], as well as economic opportunities, that is on the availability of investment to increase capacity.

Let us consider the work of the method on the example of NORTHERN MPP open pits group: Pervomaisky and Annovsky open pits, which extract ferrous quartzites for their processing into iron ore concentrate. Taking into account the mining and economic capabilities of the plant, as well as the need for iron ore concentrate in the foreign and domestic markets, design institutes in 2008 together with the plant established an ore mining strategy for the next 30 years:

- For Pervomaysk mine – 23-30 m. t/y;
- For Annovsk mine – 10-15 m. t/y.

Stripping operation scopes which ensure the productivity achievement are:

- For Pervomaysk mine – 17,71-21,6 m. m^3/y (n=0,76-0,78 m^3/t);
- For Annovsk mine – 15,8-16,5 млн. $м^3$/год (n=1,55-1,57 m^3/t).

It is advisable to make a comparative evaluation of options, using as a criterion for evaluating the maximum net present value of cash flows

$$\sum_{t=1}^{T}\sum_{k=1}^{K}\sum_{i=1}^{I}\left(\frac{\sum_{j=1}^{J}\left(A_{p\,tkij}\cdot\gamma_{к\,tkij}\frac{\beta_{(tkij)}}{\beta_{(tkj)}}p_{tk}\right)-c_{P\,tki}^{c.var.}\cdot\sum_{j=1}^{J}\left(A_{p\,tkij}\cdot\gamma_{k\,tkij}\right)-FC_{tki}^{c.const}}{(1+E)^{t}}-\right.$$

$$\left.-\frac{\sum_{j=1}^{J}\left(\left(a_{o(tkij)}^{c.var.}+n_{ij}\cdot b_{(tkij)}^{c.var}\right)\cdot A_{p\,tkij}+FP_{tkij}^{c.const.}+F_{ij}^{var}\right)}{(1+E)^{t}}\right)\times(1-N)-$$

$$-\sum_{t=1}^{T}\frac{\left(\Delta V_{lag(tij)}^{p}+\Delta Q_{rm(ij)}\right)k_{incr}+K_{t}}{(1+E)^{t}}\rightarrow max \qquad (1)$$

Iron ore concentrate demand can be decreased or increased. Therefore, the change in indicator (1) in the case of a forced change in the volume of concentrate production in one or another direction was studied from the achieved level of ore production in the Annovsky and Pervomaisky open pits. For this purpose, for each variant of ore open pit productivity within the range of possible options, the parameters of the development system (width of the work site and the length of the active extraction front, providing the normative ore reserves, ready for extraction [13]) (which are depended on the overburden coefficient), were determined. At that, the issue of ore extraction productivity set level achievement was first considered, taking into account the current condition of

mining operations in open pits [14] (as of 01.01.2014), and also operations mode change depending on ore extraction productivity change [15]. Calculation results are shown in the table 1. In addition the calculation results are presented in diagram 1.

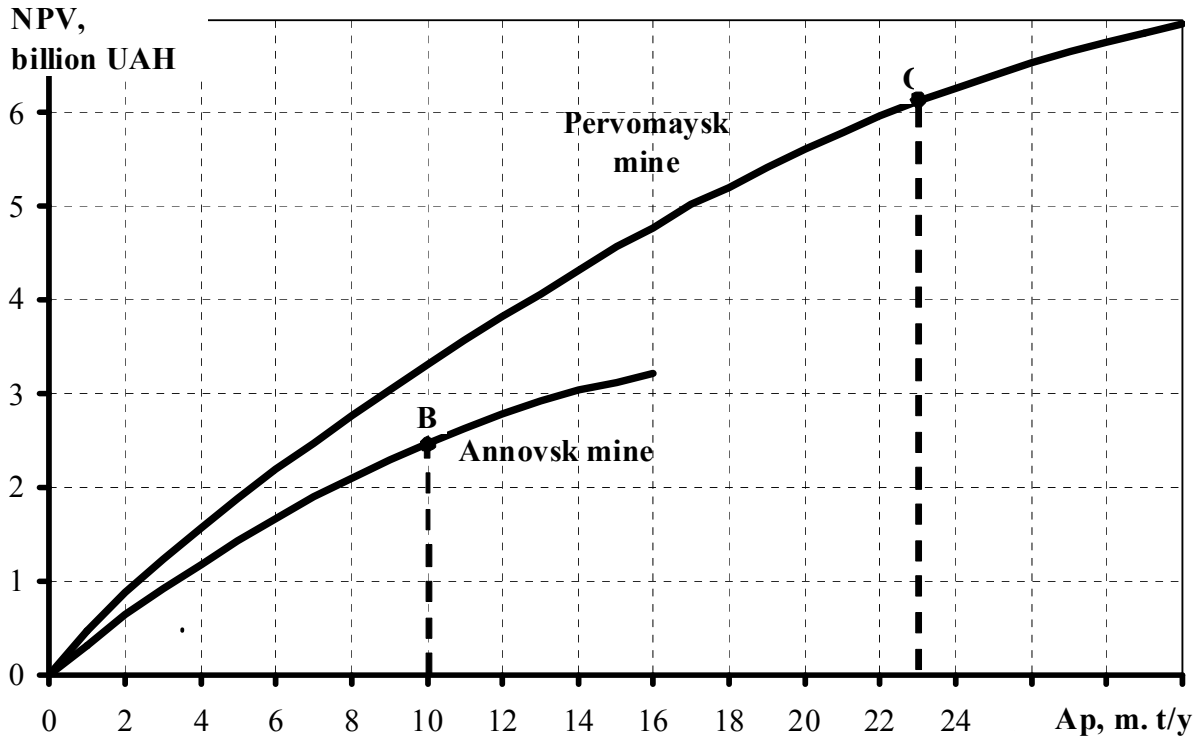

Fig. 1. Change of net present value of cash flow (NPV) according to the ore demand of the open pits of Northern MPP

Table 1

Initial data and results of proceeds calculation of Northern MPP

Items	Pervomaysk mine					Annovsk mine				
	A_{p1}	A_{p2}	$A_{p.str}$	A_{p4}	A_{p5}	A_{p1}	A_{p2}	$A_{p.str}$	A_{p4}	A_{p5}
1. Ore extraction volume, m. t/y (A_p)	21	22	23	24	25	8	9	10	11	12
2. Concentrate output, fraction (γ)	0,42	0,42	0,42	0,42	0,42	0,38	0,38	0,38	0,38	0,38
3. Concentrate production volume, m. t/y (A_k)	8,8	9,2	9,7	10,1	10,5	3	3,4	3,8	4,2	4,6
4. Stripping ratio, m^3/t	0,65	0,69	0,72	0,75	0,81	1,65	1,71	1,83	1,95	2,06
5. Annual net present value of cash flow, billion hryvnia (NPV)	4,41	4,57	4,74	4,91	5,02	1,1	1,21	1,28	1,34	1,4

Points B and G in this diagram characterize technological and economic figures of mines operation with ore extraction productivity, which is set in the strategy of Plant (as of 01.01.2014):

- For Pervomaysk open pit – A_p = 23 m. m^3/y, n_p=0,72 m^3/t, γ_p=0,42;
- For Annovsk open pit – A_p = 10 m. m^3/y, n_A=1,83 m^3/t, γ_A=0,39.

The analysis of Figure 1 shows that with the increase in productivity of both Pervomaisky and Annovsky open pits, despite the increase in overburden coefficients, the profit from the production of concentrate increases. Slope of curves shows that the more is slope angle, more revenue will be obtained by Plant from the same increase of mine productivity. Lines 1 and 2 slopes are different depending on the performance value. It means that the same increase of ore extraction volumes from Annovsk and Pervomaysk mines won't ensure the same increase of NPV for Plant. In this case, the increase of the net present value of cash flow of the plant will be affected by the level of productivity at the estimated time.

For illustrative purposes, we graphically represent the dependence of the increase in the net present value of cash flows (NPV) on the increase in productivity (ΔAp) of the Annovsky (2) and Pervomaisky (1) open pits (Fig. 2).

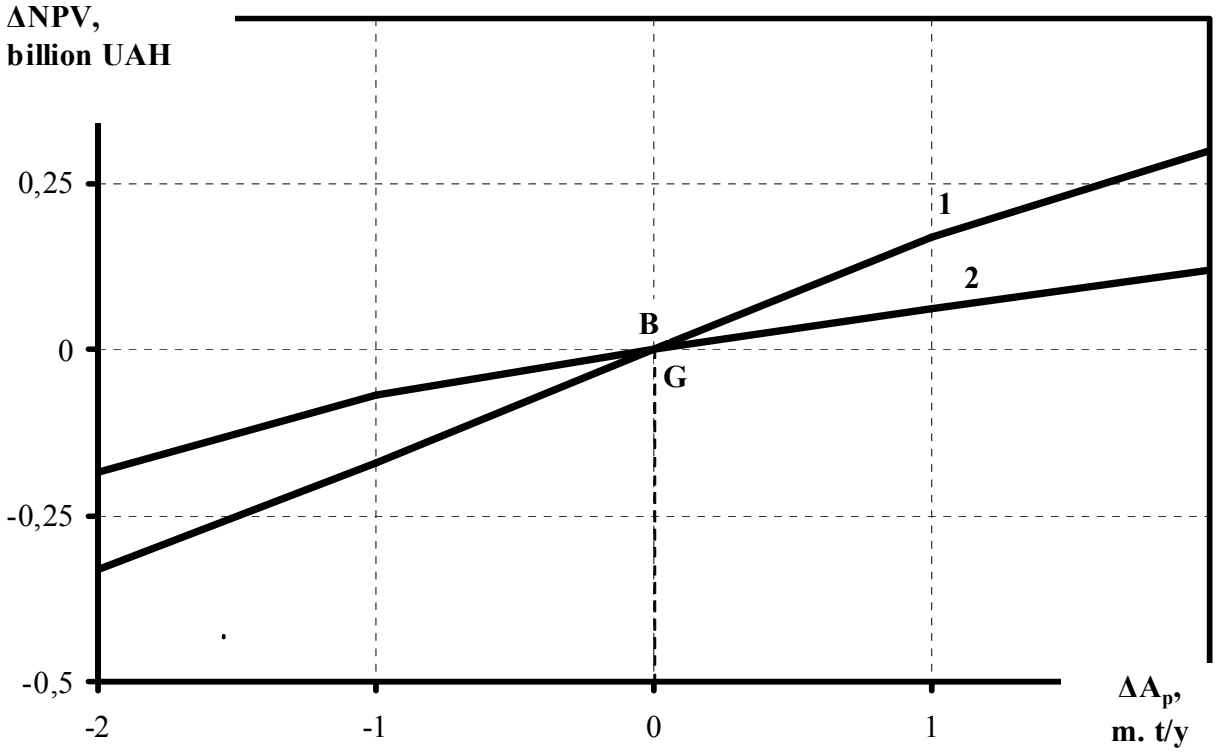

Fig. 2. Change of annual net present value of cash flow ΔNPV according to the shifts in ore productivity A_p of open pits: 1 – Pervomaisky; 2 – Annovsky.

Figure 2 shows that with this variant of combining the productivity of Pervomaisky and Annovsky open pits, increasing the productivity of Pervomaisky open pit will provide greater economic efficiency of development of the raw material base of the plant compared to a similar increase in productivity on Annovsky open pit.

Pervomaysk mine productivity increase by 1 m.t/y will bring to NPV increase by 200% versus this figure increase for Annovsk mine. At the same time along with ore mining decrease by 1 m. t/y in Pervomaysk mine, net profit loss will be also higher. Therefore in case of consideration the issue of mine designed ore mining productivity reduction (less than 33 m. t/y), first of all it is required to decrease productivity of Annovsk mine. In case of ore mining productivity increase (more than 33 m. t/y), first of all it is required to increase Pervomaysk mine productivity up to maximum possible volumes and then, if it isn't enough, to increase productivity of Annovsk mine.

In case of ore mining productivity reallocation without any changes in general strategy for final product production, it is required to consider that net profit change won't be even to ore mining productivity: net profit is changed the least when mine productivity is increased than when it is decreased.

At the ore extraction productivity increase in Pervomaysk mine by 1 m.t/y, increase of NPV will be 155 m.UAH. At the same time, at ore extraction productivity decrease in Annovsk mine will cause loss of NPV for this mine by 56 m. UAH. The difference between increase and loss of NPV by ore mining volumes reallocation by 1 m.t/y for Plant will be - 177%; by 2 m. t/y will be - 63%; by 3 m. t/y will be - 19%.

Based on abovementioned, it is obvious that the ore extraction designed productivity in the volume of 33 m.t/y is better to fulfill by increasing the productivity of Pervomaysk mine by 1 m. t/y and decreasing the productivity by the same value in Annovsk mine. Then, ore extraction volumes will be reallocated as following: Pervomaysk mine – 24 m. t/y, Annovsk mine – 9 m. t./y. In this case, only the redistribution of the open pit ore productivity without changing the overall strategy of production of marketable products will increase the net annual income of the plant.

A comparison of the indicators of optimal productivity of Northern MPP open pits group (as on 01.01 2014) with the designed one showed that due to the redistribution of annual volumes of ore production in the optimal mode, it is possible to increase the operational efficiency of the plant.

The productivity of group of mining and processing plants, that are part of a mining company, is redistributed along the same line.

4. Conclusions.

A method of redistributing the productivity of a group of open pits, that are part of the mining and processing plant when the need for iron ore products changes, which takes into account the relationship between the mode of mining operations and ore productivity, based on the condition of supporting the standards for reserves, ready for extraction.

On the example of Annovsky and Pervomaisky open pits, which are part of the Northern MPP, the redistribution of ore productivity was performed without changing the general strategy of production of the plant's marketable products. Calculations have shown that the redistribution of ore productivity between the Pervomaisky and Annovsky open pits only on 1 million tons/year towards the Pervomaisky open pit will increase the profit of the Northern MPP by UAH 96 million.

References

1. Романенко А.В. Обзор и анализ проектных решений по технологии открытых горных работ на глееватском карьере ПАО «ЦГОК» / А.В. Романенко, А.Е.Биленко, В.В.Терещенко, В.Г.Пшеничный // Гірничий вісник КНУ: збірник наук. праць, Вип. 95 (1). - Кривой Рог, 2012.- С.25-31.

Romanenko A., Bilenko A., Tereshchenko V., & Pshenichnyj V. (2012). Obzor i analiz proektnyh reshenij po tekhnologii otkrytyh gornyh rabot na gleevatskom kar'ere PAO «CGOK». *Girnichij visnik KNU: zbirnik nauk. prac'*, 95 (1), 25-31.

2. Близнюков В.Г. Improvement of technical criteria for comparative evaluation of mining operation options of iron ore open pits / В.Г. Близнюков, С.А. Луценко // Науковий вісник НГУ. – Д.:ДВНЗ «НГУ», 2017. - №1. С. 44-49.

Bliznyukov V., & Lucenko S. (2017) Improvement of technical criteria for comparative evaluation of mining operation options of iron ore open pits. *Naukovij visnik NGU*, №1, 44-49.

3. Луценко С. А. Исследование режима горных работ, обеспечивающего достижение максимально возможной производительности карьера по руде / С.А. Луценко // Вісник НТУУ "КПІ". – Київ. – 2017. - Вип. 34. – С34-40.

Lucenko S. (2017). Issledovanie rezhima gornyh rabot, obespechivayushchego dostizhenie maksimal'no vozmozhnoj proizvoditel'nosti kar'era po rude. *Visnik NTUU "KPI"*, 34, 34-40.

4. Lucenko S. (2017). Open pits productivity control along with iron ore products demand variation. *Quality – Access to Success*, 18(S1), 226-230.

5. Арсентьев А.И. Стратегия и тактика проектирования открытых горных работ / А.И. Арсентьев // Горный журнал, №11.- Москва, 2008. - С.54-58.

Arsent'ev A. (2008). Strategiya i taktika proektirovaniya otkrytyh gornyh rabot. *Gornyj zhurnal*, №11, 54-58.

6. Косолапов А.И. О возможности управления производственной мощностью карьеров при вариации спроса на их продукцию при разработке крутопадающих месторождений / А.И. Косолапов, А.И. Пташник // Международный журнал прикладных и фундаментальных исследований, №6. – Красноярск, 2011.- С. 33-36.

Kosolapov A., & Ptashnik A. (2011). O vozmozhnosti upravleniya proizvodstvennoj moshchnost'yu kar'erov pri variacii sprosa na ih produkciyu pri razrabotke krutopadayushchih mestorozhdenij. *Mezhdunarodnyj zhurnal prikladnyh i fundamental'nyh issledovanij*, №6, 33-36.

7. Ржевский В.В. Научные основы проектирования карьеров / В.В.Ржевский, М.Г.Новожилов, Б.П.Юматов. – М.: Недра, 1971.– 600 с.

Rzhevskij V., Novozhilov M., & Yumatov B. (1971) Nauchnye osnovy proektirovaniya kar'erov. M.: Nedra.

8. Арсентьев А.И. Производительность карьеров / А.И.Арсентьев. – Санкт-Петербургский горный институт. СПб, 2002.– 85 с.

Arsent'ev A. (2002) Proizvoditel'nost' kar'erov. Sankt-Peterburgskij gornyj institut. SPb.

9. Шпанский О.В. Проектирование производственной мощности карьеров: Учеб. пособие / О.В.Шпанский, Д.Н.Лигоцкий, Д.В.Борисов. – Санкт–Петербургский государственный горный институт. СПб, 2004. – 96 с.

Shpanskij O., Ligockij D., & Borisov D. (2004). Proektirovanie proizvodstvennoj moshchnosti kar'erov. Sankt–Peterburgskij gosudarstvennyj gornyj institut. SPb.

10. Близнюков В.Г. Определение максимальной производительности карьера при установленном режиме горных работ / В.Г. Близнюков // Разработка рудных месторождений . – Киев: Изд. «Техніка». - 1975. – Вып. 19. – С. 11-18.

Bliznyukov V. (1975). Opredelenie maksimal'noj proizvoditel'nosti kar'era pri ustanovlennom rezhime gornyh rabot. *Razrabotka rudnyh mestorozhdenij*, 19, 11-18.

11. Мельников Н.В. Вопросы выбора производственной мощности карьера / Н.В.Мельников, К.Е.Виницкий, В.С.Меньшов, Э.И.Реентович. - Москва: «Наука», 1971. - с.166.

Mel'nikov N., Vinickij K., Men'shov V., & Reentovich E. (1971). Voprosy vybora proizvodstvennoj moshchnosti kar'era. Moskva: «Nauka».

12. Луценко С.А. Разработка метода определения максимальной, по горным возможностям, производительности карьера по руде / С.А. Луценко // Геотехническая механика. – Днепропетровск, 2017. - №130. С. 168-175.

Lucenko S. (2017). Razrabotka metoda opredeleniya maksimal'noj, po gornym vozmozhnostyam, proizvoditel'nosti kar'era po rude. *Geotekhnicheskaya mekhanika*, №130, 168-175.

13. Луценко С.А. Определение ширины рабочей площадки и длины фронта горных работ при изменении производительности карьера по руде / С.А. Луценко // Збірник наукових праць НГУ. - Дніпропетровськ: Національний гірничий університет, 2017. - №50. С. 63-69.

Lucenko S. (2017). Opredelenie shiriny rabochej ploshchadki i dliny fronta gornyh rabot pri izmenenii proizvoditel'nosti kar'era po rude. *Zbirnik naukovih prac' NGU*, №50, 63-69.

14. Близнюков В.Г. Технологический критерий комплексной оценки режима горных работ и производительности карьера по руде / В.Г. Близнюков, С.А. Луценко, Ю.М. Навитний, И.В. Баранов, О.Ю. Близнюкова // Вісник Криворізького національного університету: зб. наук. праць. – Кривой Рог, 2013 – С. 268-271.

Bliznyukov V., Lucenko S., Navitnij YU., Baranov I., & Bliznyukova O. (2013). Tekhnologicheskij kriterij kompleksnoj ocenki rezhima gornyh rabot i proizvoditel'nosti kar'era po rude. *Visnik Krivoriz'kogo nacional'nogo universitetu: zb. nauk. prac'*, 268-271.

15. Вилкул Ю.Г. О проблеме отставания вскрышных работ в железорудных карьерах / Ю.Г.Вилкул, С.А. Луценко, О.Ю. Близнюкова // Металлургическая и горнорудная промышленность, №3. – 2013 – С. 92-96.

Vilkul Y., Lucenko S., Bliznyukova O. (2013). O probleme otstavaniya vskryshnyh rabot v zhelezorudnyh kar'erah. *Metallurgicheskaya i gornorudnaya promyshlennost'*, №3, 92-96.