Technique for Justifying the Amount of the Redundant Developed Reserves Considering the Content of Metal in the Mining Ore

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Abstract. An analysis of the preparedness of reserves in the Kazakhstan quarries has shown that in a real production process, periods of stable mining unit operation alternate with failures when the ore mass is not fully or partially supplied over the estimated time in the targeted amount and quality. To eliminate the production process breakdown and ensure continuity and consistency of the individual mining cycle stages, redundant mining units with developed reserves should be provided.

A technique for justifying the prepared ore reserves is proposed considering the variability of the active mining face parameters based on a statistical analysis of data of operating mining enterprises. To determine the dependence of the produced raw material qualitative composition homogeneity on the number of open pitiable mining faces, the actual weekly-daily schedules of the mining operations of several quarries (test pit 1) and (test pit 2) have been used. It is assumed that under the conditions of an operating mining enterprise, some averaging process parameters independent of the number of mining units may be considered constant and determined based on the operation data. Therefore, the solution to the problem of determining the effect of the number of mining units on the ore flow averaging level can be simplified.

The dependence of the useful component content on the number of operating mining units has been studied. A regression analysis of statistical data has been performed. Based on empirical dependencies, formulas for simplified calculating the amount of redundant developed reserves considering the required quality of the extracted ore have been obtained.

1. Introduction

Currently, one of the important problems facing mining enterprises is ensuring the systematic and smooth operation of mines and the feasible use of production capacities. In this sense, the amount and ratio of redundant developed reserves significantly affect enterprise performance.

One of the main conditions to achieve systematic and smooth productivity of a quarry is the creation of redundant developed mineral reserves. These reserves allow developing the horizon for a certain period, regardless of the overlying ones.

In the practice of operating quarries, the amount and ratio of developed and ready-to-mine reserves depend on the number of operating mining units simultaneously involved in different mining stages [1]. The interrelation of the number of mining units operating at various stages of the mining cycle is one of the conditions required to form the mining face ensuring the smooth and reliable operation of the entire mine. The amount of the mining face reserve impacts directly on the stability of the
extracted ore quality and the ability to manage it in the case of sharp fluctuations in the content of useful components in the ore body. A reduction in the amount of the mining unit reserves may cause a disturbance in the production rhythm of the mine and failure to meet the production plans, and unreasonably increased mining face reserves entail an increase in costs due to additional expenses for maintaining the mine openings.

In this regard, improving the technique for determining the amount of the redundant developed ore reserves based on the evaluation of the active open-pit mining face parameters is relevant and may contribute to improving the deposit development efficiency.

2. Literature review
The mining face development issues, the regulation of the amount of the ready-to-mine reserves in working benches, the optimal arrangement of the quarry working area, the establishment of the enterprise productivity, the increase in the mine engineering system reliability, and the regulation of the reserve preparedness standards have been considered in [2–20] and by the sectoral research institute experts, which is reflected in the Procedural Guidelines drawn up by VNIMI, VNIItsvetmet, and VIIOGEM. They specify the factors that should be considered when determining the active mining face parameters and reserve preparedness standards. However, a comparative analysis of the techniques performed for the same conditions has shown a more than one and a half times difference between the calculated mining face and reserve standards. The reason is the difference of the source databases and the standard calculation algorithms.

3. Techniques
Rationing the amount of redundant developed reserves is a technical and economic problem, in solving which the dependence of the reserve movement pattern on various conditions, as well as gains and losses associated with the reserve management mechanism should be considered. The amount of developed reserves depends on many factors, the complex consideration of which is often a very difficult task due to the deficiency or complete lack of source data for calculations.

An analysis of the preparedness of reserves in the Kazakhstan quarries has shown that in a real production process, periods of stable mining unit operation alternate with failures when the ore mass is not fully or partially supplied over the estimated time in the targeted amount and quality.

To eliminate the production process breakdown and ensure continuity and consistency of the individual mining cycle stages, redundant mining units with developed reserves should be provided.

The study idea is to use the actual data of operating enterprises to identify the dependencies determining the parameters of the rational and consistent development of mining operations to ensure stable extraction of ore reserves in the required quantity and quality while justifying the redundant developed reserves.

Research techniques included analysis of theoretical works, regulatory and procedural basis for calculating the mining face parameters and actual practical data of the deposit development, and mathematical statistics and regression analysis techniques.

Determining the rated number of mining units according to the degree of the mine preparedness for mining should be performed in conjunction with the optimization of the entire system of averaging the extracted ore since the number of operating mining faces and therefore, the number of individual ore flows are among the most important factors determining the level of averaging the qualitative composition of ore in the total flow produced by the mine.

To determine the dependence of the produced raw material qualitative composition homogeneity on the number of open pitiable mining faces, the actual weekly-daily schedules of the mining operations of the quarries (test pit 1) and (test pit 2) have been used. The variance of the actual data of metal content in the variable amounts of the extracted raw materials for a different number of mining faces is shown in Table 1.
Table 1. Actual Variance of Chromium and Iron Contents.

| Mining Unit Number | Test Pit 1 Chromium (unit fraction) | Test Pit 2 Iron (unit fraction) |
|--------------------|------------------------------------|-------------------------------|
| 2                  | 0.26                               | 0.36                          |
| 3                  | 0.20                               | 0.29                          |
| 4                  | 0.17                               | 0.25                          |
| 5                  | 0.16                               | 0.19                          |
| 6                  | 0.13                               | 0.15                          |
| 7                  | 0.12                               | 0.14                          |
| 8                  | 0.10                               | 0.13                          |

Under the conditions of an operating mining enterprise, some averaging process parameters independent of the number of mining units may be considered constant and determined based on the operation data. Therefore, the solution to the problem of determining the effect of the number of mining units on the ore flow averaging level can be simplified. A statistical analysis of the ratio of the amount of developed reserves to the number of operating mining units has been performed.

For the analyzed period of observations and variation range, the exponential approximation turned out to be preferable from the correlation coefficient point of view. The strength of relationship is significant — the correlation ratio $\eta = 0.87$, and the average approximation error $\delta = 0.05$. Figure 1 shows a plot built based on the data obtained and representing the relationship between the number of operating mining units and the metal content deviation from the average target figures, which allows drawing the following conclusion: all other things being equal, an increase in the number of mining units leads to a decrease in the quality fluctuations of the ore being mined.

Based on the actual data of the effect of the number of mining units on the average metal content in the ore being mined, an empirical formula can be obtained for approximate evaluating the variance of the averaged component content or solving the inverse problem, i.e. determining the required number of operating mining units by the required content of useful component in the total ore flow.

It is also worth noting that a similar dependence is observed when studying the effect of the mining face dimensions and, accordingly, the amount of ready-to-mine reserves on the variability of the quality and process parameters of the ore being mined: at a relatively small mining face, the average useful component content in the ore being mined may differ significantly from the set value.

Productivity fluctuations of the mining faces and the probability of their emergency failure, the unevenness of mining operations and mine openings, the variability of the qualitative composition of the mineral in the bowels, and some other factors require ensuring a certain number of redundant mining units in addition to operating ones. Ready-to-mine reserves concentrated in operating and redundant mining units should contribute to maintaining the mining faces, stable enterprise operation, the possibility of averaging the quality of ore being mined, and the smooth development of the deposit.
Figure 1. Dependence of the Metal Content Variance on the Number of Operating Mining Faces.

To meet the requirements for raw material qualitative composition uniformity, mining enterprises are often forced to have an additional number of mining faces and therefore, an additional amount of ready-to-mine reserves. In this regard, when determining the optimal amount of ready-to-mine mineral
reserves developed in the averaging mode, the requirements for stabilizing the extracted raw material qualitative composition should be considered.

The availability of mining faces and ready-to-mine reserves facilitates control over the ore mining in the averaging mode and reduces the fluctuations in the raw material quality in individual and common mine flows.

Studying the operating experience of existing quarries has shown that the number of mining units and the amount of redundant developed mine reserves are also interdependent. During the periods of stable and smooth mining, these reserves, based on effective capacities, have ensured the achievement of the required productivity at an optimal ore flow arrangement level. The data analysis has shown that the factors considered sufficiently correlate with each other and allow identifying functional dependence.

The relationship between the number of mining units and the developed reserves obtained based on the average operation data during the stable production periods at several quarries (test pit 1) and (test pit 2) (Figure 2) is a case in point.

By approximating empirical data, we obtain the below functional dependence:

\[ Q_p = (0.3 \cdot n - 0.09) \cdot k_p \]  

where:
- \( Q_p \) is the number of redundant developed reserves, tons,
- \( n \) is the number of operating mining faces, pcs,
- \( k_p \) is the reserve coefficient considering the specific conditions of the particular deposit development, adopted within 1.1÷1.5 depending on the complexity of the development conditions.

**Figure 2.** Empirical Relationship between the Number of Operating and Redundant Mining Units.

The relationship between the open-pit mining face number and the amount of developed reserves is quite definite and sufficiently reliable for use. This direct proportional relationship allows reducing the problem of determining the optimal amount of redundant developed reserves to defining the optimal number of the open-pit mining units, which, in turn, is determined by the required averaging of ore flows.
4. Results and discussion

The variability of the useful component content has been studied depending on the number of operating mining faces.

Based on the analysis of the actual data of several operating quarries, an empirical relationship has been established between the number of operating mining units and developed reserves. Based on this dependence, in the aspect of averaging ore flows, an empirical formula has been obtained that allows reliably calculating the amount of developed reserves for a known established number of operating mining faces.

Studying the distribution of amounts of developed reserves depending on the number of operating mining faces allowed determining quantitative indicators of their changes, setting their values when planning mining operations, and evaluating the feasibility of forming redundant mining units with a sufficient level of reliability.

The empirical dependencies obtained are generally close to theoretical calculations. The empirical distribution of the varying attribute approaches the theoretical one at sufficiently large sample size.

5. Conclusion

The proposed technique for determining the redundant developed reserves is quite simplified but can be used to promptly determine the amount of reserves in the deficiency or lack of the source data for calculation using available techniques.

Formula (1) has been proposed for determining the number of redundant mining units ensuring the absence of a shortage of developed reserves with sufficient reliability.

The empirical dependence obtained based on regression analysis of statistical data allows solving the problem of determining the required number of operating mining units to achieve the required quality in the total ore flow.

The calculated data obtained indicate that depending on the required level of reliability of ensuring the given productivity of the test mine, 11 to 18 mining units should simultaneously operate. This corresponds to the ready-to-mine reserves for 8 to 14 months. When optimizing the actual mining face by the developed reserves to the recommended values, an economic effect of 6,400 to 9,100 CU/t can be obtained due to minimizing process failures caused by the lack of developed reserves and stabilizing the ore flow quality, which favorably affects the useful component recovery degree at a processing plant.

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