Research of the influence of the excavating and automotive equipment complexes parameters on the speed of faces advance

D V Kuznetsov* and A I Kosolapov

Siberian Federal University, 95, pr. Im. Gazety Krasnoyarsky Rabochy, Krasnoyarsk, 660025, Russia

*E-mail: KuznetsovDV@mail.ru

Abstract. The article presents the results of the research on the equipment complexes parameters impact assessment with electric and hydraulic excavators and dump trucks on deposits development intensity. The classification of deposits according to the relative difficulty of development is introduced. For the open pits of each of the identified five classes, the possible speed of faces advance is determined with the diversity of equipment parameters, deposits parameters and panel blocks.

1. Introduction

Open-cut mineral deposits mining predetermines the continuing innovation and pit equipment power expansion due to large volumes of mining and transportation works. Because of the fact that technological features almost do not limit its capacity and power supply, a lot of mining enterprises have achieved a high level of labor productivity, increasing requirements for solid mineral deposits are provided with greater economy and efficiency [1].

Alongside with that, such development is connected with an increase in the open-pits depth, their size in plan and movement to remote areas with a climate complicating technology. Selection of optimal equipment parameters for certain conditions is quite difficult [2, 3], despite the wide development of available methods [4, 5].

First of all, for projecting and conducting mining operations at the present stage, it is necessary to determine the conditions for rational use of technical advantages and parameters of a particular equipment, to supplement the decisions on the pits development intensity justification in plan and depth, along with the connection to all key parameters of the pit space as well as the physicotechnical characteristics of the developed solids.

Therefore, in this article, in reliance on the previously suggested classification of deposits according to the relative development difficulty [6], the authors have summarized the results of similar research. All numerical calculations are valid for the diversity of excavators and dump trucks presented on the Russian market, and while conducting operations in a severe climate conditions [1] with possible temperature variations, precipitation and other factors.
2. The theory of research

It is known that the technical and economic efficiency of open-pit mining is mostly predetermined with the ability to control the pits operating area development intensity in plan and depth [7, 8], which primarily depends on the speed of quarry faces advance [9, 10].

Therewith the speed of front faces advance \( V, \text{m/day} \) at the corresponding open-pit bench width and daily productivity of the excavating equipment complexes can be solved by the formula:

\[
V = \frac{Q}{A \cdot h}
\]  

(1)

where \( Q \) - daily productivity of excavating equipment complexes, \( m^3/day \); \( A \) – bench width, \( m \); \( h \) – height of the highwall, \( m \).

Taking this into consideration, the time of the panel block processing \( t, \text{day} \) of the preset length is:

\[
t = \frac{l}{V}
\]  

(2)

where \( l \) - the panel block length, \( m \)

The bench width \( A \) and the height of the highwall h taken into account in formula (1) are mainly predetermined with the possible height, depth, digging radius and overall dimensions of the excavators, as well as with the ratio of the dimensions of the excavating and drilling entry ways.

The main factors affecting complex productivity \( Q \) are:
- excavator bucket capacity;
- lifting capacity of the dump truck and the number of excavating cycles (buckets loaded into the dump truck);
- excavation cycle time;
- time of dump trucks exchange in the face;
- strength characteristics of solids;
- length of excavating unit;
- technical reliability and service life;
- climatic conditions, etc.

To improve the use of equipment and organization of work on the highwall, it is advisable to place the smallest number of excavation complexes. The length of the panel blocks l should be set to ensure uninterrupted withdrawal and loading in the benches. For road transport on pits, its value is on average 300-600 m. Moreover, the minimum limitation is restricted according to the conditions for the production of drilling-and-blasting and transport operations.

Consequently, for specific pit and equipment parameters it is possible to determine the quarry faces parameters. Taking into account the possible change in the productivity of the equipment, the speed of their advance ensuring the greatest efficiency of the deposit development can be calculated either.

3. Classification of deposits by relative development difficulty

According to the results of previously conducted works, it has been stated that the main factors affecting the labor intensity as well as technical and economic efficiency of the deposit development are: the ultimate compressive strength of solids \( (\sigma, \text{MPa}) \); solid density \( (\gamma, \text{t/m}^3) \); average size of the structural block \( (a, \text{m}) \); pit depth \( (H, \text{m}) \); ore and overburden transportation distance \( (L, \text{km}) \); harsh climate stiffness \( (J, \text{score}) \) [2, 6]. At the same time, five classes with the corresponding area of these indicators change can be distinguished for the entire variety of deposits (see table 1).

Alongside with that, mineral deposit mode of occurrence, pit depth \( H \), the angles of the pit wall slopes, determined primarily by the strength characteristics of the solids and the indicators \( \sigma, \gamma \) influence on the number and parameters of faces as well as equipment parameters.
### Table 1. Dump truck performance decline level.

| Class of deposits according to the difficulty of development | Category | Deposits parameters | Deposits parameters |
|---------------------------------------------------------------|----------|--------------------|--------------------|
|                                                               |          | $\sigma$, MPA      | $\gamma$, t/m$^3$  |
| I. Easily developed                                           | 1, 2, 3, 4, 5 | $\leq 40$ | $\leq 1.8$ |
| II. Medium development difficulty                             | 6, 7, 8, 9, 10 | $>40$ | $>1.8$ |
| III. Hard to be developed                                     | 11, 12, 13, 14, 15 | $>80$ | $>2.4$ |
| IV. Very hard to be developed                                 | 16, 17, 18, 19, 20 | $>120$ | $>2.9$ |
| V. Extremely hard to be developed                             | 21, 22, 23, 24, 25 | $>160$ | $>3.3$ |

Moreover, studies have established that along with the height of excavators digging and the overall width of dump trucks, and respectively the height of highwalls and the width of in-pit roads, the area of the pit in plan varies to 40% at classes.

### 4. Estimation of parameters and speed of excavation faces advance

Formula 1 has been used to estimate impact assessment of equipment parameters and productivity on the speed of faces advance of established sizes. The dependencies obtained accordingly are presented as examples in graphs (see Figures 1 and 2).

![Figure 1. Influence of average electric excavator bucket capacity on drilling open-pit bench width and maximum height of the highwall during IV class of difficulty deposit development and lifting capacity of dump truck: 1 $- q = 90$ t; 2 $- q = 180$ t; 3 $- q = 320$ t.](image-url)
Figure 2. Influence of average electric excavator bucket capacity on speed of faces advance movement during IV class of difficulty deposit development and lifting capacity of dump truck: 1 – \( q = 90 \) t; 2 – \( q = 180 \) t; 3 – \( q = 320 \) t.

Here, for the conditions of the IV class of deposits difficulty (see Table 1) and the equipment complexes parameters with electric excavators, the width of the drilling entry way \( A \) is taken to be equal to two excavators, the height of the highwalls \( h \) has been set to be equal to the maximum excavators digging height. In possible combinations of excavating complexes, the number of buckets loaded by the excavator into the dump truck has been taken with allowance to the known recommendations from 3 to 7.

Thus, each bucket capacity range of the excavator \( E \) corresponds to a certain load capacity range of the self-dump truck \( q \). The version of the excavating-automobile complex with the smallest excavator bucket capacity has a lower lifting capacity of the dump truck and productivity.

Analysis of the graphs shows that with an increase in the capacity of the bucket \( E \), the possible speed of faces advance \( V \) increases, as well as with a corresponding increase in the bench width height of the highwalls.

5. Results and conclusions

The results of the research have been summarized in numerical form (see Tables 2 and 3). The obtained data show a possible faces advance speed variation change at the given height of the highwalls and the length of the panel blocks according to the classes of deposits.

The influence of the panel block length on the operations organization and the level of excavator productivity here is determined based on the previously established dependencies [8]: at a block length of 600 m, productivity is accepted as maximum, at a block length of 500 m - reduced by 7-15 %, at a block length of 400 m - by 15-27 % and at a block length of 300 m - by 27-45 %. This takes into account the need for non-productive (auxiliary) operations and the feed for dump trucks loading according to various schemes, power lines switchover and other complicating factors.

The specified height of the highwalls is limited with the maximum digging height of the excavators. While conducting operations with highwalls of 5 m high for electric excavators with a bucket capacity of 5-12 m\(^3\), the table 2 data must be increased by 2 times. The same comes for hydraulic excavators with a bucket capacity of 10-25 m\(^3\) – the table 3 data must be increased by 2 times. While conducting operations with highwalls of 10 m high for electric excavators with a bucket capacity of 12-60 m\(^3\), the table 2 data must be increased by 1,5 times as well as for hydraulic excavators with a bucket capacity of 25-50 m\(^3\) – the table 3 data must be increased by 1,5 times.

When operating equipment in the severe climate zone [1], the table 2 data should be reduced by 0-10 % (in April-October), by 10-15 % (in March, November), by 15-20 % (in December-February). Table 3 data should be reduced by 0-20 % (in April-October), by 20-30 % (in March, November), by 30-40 % (in December-February).
Table 2. Electrical excavators face advance speed.

| Bucket capacity $E$, $m^3$ | Block length $l$, m | Height of highwall 10 m | I | II | III | IV | V |
|----------------------------|---------------------|-------------------------|---|---|---|---|---|
| 300                        | 11,4-20,6           | 10,7-19,5               | 9,9-18,4 | 9,4-17,8 | 9,2-15,9 |
| 400                        | 13,1-23,7           | 12,3-22,5               | 11,3-21,2 | 10,9-20,5 | 10,6-20,0 |
| 500                        | 14,5-26,1           | 13,5-24,8               | 12,5-23,4 | 12,0-22,6 | 11,7-22,1 |
| 600                        | 15,6-28,2           | 14,6-26,7               | 13,5-25,2 | 12,9-24,4 | 12,7-23,9 |
| 5-12                       |                     |                         |       |       |       |       |
| 300                        | 14,1-19,2           | 13,3-18,1               | 12,4-17,0 | 11,9-16,3 | 11,6-15,9 |
| 400                        | 16,3-22,1           | 15,3-20,8               | 14,3-19,5 | 13,7-18,7 | 13,4-18,3 |
| 500                        | 18,0-24,4           | 16,9-23,0               | 15,8-21,5 | 18,0-24,4 | 14,8-20,2 |
| 600                        | 19,4-26,3           | 18,2-24,8               | 17,0-23,2 | 16,4-22,3 | 15,9-21,8 |
| 12-20                      |                     |                         |       |       |       |       |
| 300                        | 18,5-25,7           | 17,4-28,5               | 16,3-22,9 | 15,7-22,1 | 15,3-21,6 |
| 400                        | 21,2-29,5           | 20,0-28,5               | 18,7-26,3 | 18,0-25,4 | 17,6-24,8 |
| 500                        | 23,4-32,6           | 22,1-29,4               | 20,7-29,1 | 19,9-28,0 | 19,4-27,4 |
| 600                        | 25,3-35,2           | 23,8-31,7               | 22,3-31,3 | 21,5-30,2 | 21,0-29,6 |
| 20-30                      |                     |                         |       |       |       |       |
| 300                        | 27,9-33,9           | 25,8-32,3               | 24,3-30,5 | 23,4-29,5 | 22,9-28,9 |
| 400                        | 32,1-39,0           | 29,7-37,1               | 27,9-35,1 | 26,9-33,9 | 26,3-33,2 |
| 500                        | 35,5-43,1           | 32,8-41,0               | 30,8-38,7 | 29,7-37,4 | 29,1-36,6 |
| 600                        | 38,3-46,5           | 35,4-44,2               | 33,2-41,8 | 32,0-40,4 | 31,3-39,5 |
| 30-40                      |                     |                         |       |       |       |       |
| 300                        | 38,1-45,2           | 35,9-43,2               | 34,4-41,0 | 33,4-39,8 | 32,7-39,1 |
| 400                        | 43,8-52,0           | 41,3-49,7               | 39,6-47,2 | 38,4-45,8 | 37,6-44,9 |
| 500                        | 48,3-57,4           | 45,6-54,9               | 43,7-52,1 | 42,4-50,6 | 41,6-49,6 |
| 600                        | 52,1-61,9           | 49,2-59,2               | 47,2-56,2 | 45,7-54,5 | 44,8-53,5 |
| 40-60                      |                     |                         |       |       |       |       |

Table 3. Hydraulic excavators face advance speed.

| Bucket capacity $E$, $m^3$ | Block length $l$, m | Height of highwall 5 m | I | II | III | IV | V |
|----------------------------|---------------------|------------------------|---|---|---|---|---|
| 300                        | 23,3-31,6           | 20,8-29,4              | 19,3-27,1 | 18,5-25,9 | 18,0-25,2 |
| 400                        | 25,7-36,3           | 24,0-33,8              | 22,2-31,2 | 21,2-29,8 | 20,7-28,9 |
| 500                        | 28,4-40,1           | 26,5-37,3              | 24,5-34,5 | 23,4-32,9 | 22,9-32,0 |
| 600                        | 30,6-43,3           | 28,5-40,2              | 26,5-37,2 | 25,3-35,5 | 24,7-34,5 |
| 5-10                       |                     |                         |       |       |       |       |
| 300                        | 21,0-38,1           | 19,3-35,8              | 17,6-33,5 | 16,8-32,2 | 16,4-31,0 |
| 400                        | 24,1-43,9           | 22,2-41,2              | 20,3-38,5 | 19,3-37,0 | 18,8-35,6 |
| 500                        | 26,7-48,4           | 24,5-45,5              | 22,4-42,5 | 20,7-48,4 | 20,8-39,4 |
| 600                        | 28,8-52,3           | 26,4-49,1              | 24,2-45,9 | 23,0-44,1 | 22,4-42,5 |
| 10-25                      |                     |                         |       |       |       |       |
| 300                        | 23,3-35,3           | 22,5-31,6              | 21,1-29,7 | 20,3-28,7 | 19,8-28,0 |
| 400                        | 27,4-38,5           | 25,8-36,4              | 24,3-34,2 | 23,4-33,0 | 22,8-32,2 |
| 500                        | 30,2-42,6           | 28,5-40,2              | 26,8-37,7 | 25,8-36,4 | 25,2-35,6 |
| 600                        | 32,6-45,9           | 30,8-43,3              | 28,9-40,7 | 27,8-39,3 | 27,2-38,4 |
| 25-30                      |                     |                         |       |       |       |       |
| 300                        | 28,3-34,7           | 26,8-33,0              | 25,2-31,5 | 24,4-30,2 | 23,7-29,6 |
| 400                        | 32,6-39,9           | 30,8-38,0              | 29,0-36,2 | 28,0-34,8 | 31,8-34,0 |
| 500                        | 36,0-44,0           | 34,0-41,9              | 32,1-40,0 | 31,0-38,4 | 35,1-37,6 |
| 600                        | 38,8-47,5           | 36,7-45,2              | 34,6-43,1 | 33,4-41,4 | 37,9-40,5 |
| 30-50                      |                     |                         |       |       |       |       |
Therefore, it can be concluded that mining equipment parameters and intensity rates of mining at pits are organically related, on the one hand, to pits parameters as well as to physical and technical characteristics of subsurface rocks according to deposits classes, and to technology and production processes organization on the other. As the length of the panel blocks increases, the speed of the excavating faces advance increases. Equipment complexes with hydraulic excavators are more portable in comparison with electric ones, they have smaller sizes and bench width. Consequently, in favorable climatic conditions this makes it possible to achieve a higher faces advance speed.

References
[1] Kuznetsov D, Kosolapov A and Malofeev D 2016 Equipment complexes for pits in harsh climatic conditions (Deutschland: LAP Lambert Academic Publishing)
[2] Burt C N and Caccetta L 2014 Equipment Selection for Surface Mining: A Review Interfaces 44(2) 143-62
[3] Burt C N and Caccetta L 2018 Equipment Selection for Mining: With Case Studies (Cham: Springer International Publishing)
[4] Komlenovich D 2017 Multi-criteria approach to selection of mining equipment Mining 2 10-9
[5] Yavuz M 2015 Equipment Selection based on the AHP and Yager’s method J. Southern African Institute of Mining and Metallurgy 115(5) 425-33
[6] Kuznetsov D V and Kosolapov A I 2020 Economic and technological aspects interrelation between open pit depth and mining transport parameters Izvestia vysshikh uchebnykh zavedenii. Gornyi zhurnal 3 87-95
[7] Rakishev B R 2003 Open mining works. Working pit zone and its parameters Mining Zhurnal 3 17-21
[8] Kuznetsov D V and Kosolapov A I 2018 Study of the dynamics of mining equipment concentration in deep pits of the North Izvestia Vuzov Mining Zhurnal 1 22–9
[9] Rzhhevsky B 2010 Technology and Integrated Mechanization Open Mining Works (Moscow: Librocom)
[10] Rzhhevsky B 2010 Production Processes Open Mining Works (Moscow: Librocom)