DOI: *10.25515/PMI.2018.1.56*

UDC 622.23

IMPROVED ESTIMATION OF OPEN PIT EXCAVATOR CAPACITY

Sergey N. ZHARIKOV
Institute of Mining, Ural branch of RAS, Yekaterinburg, Russia

The paper addresses issues related to estimation of operational time for open pit excavators during truck loading operations. The author analyzes the method of annual capacity estimation and highlights disagreements in different ways of operational time logging. Recommendations are offered concerning estimation of excavator capacity taking into account its repair cycle. The paper contains an analysis of the cyclical nature of various types of maintenance in the interval between capital repairs as a function of operational time. Guidelines are proposed that allow to calculate annual production days of the excavator with regards to the repair cycle and adjusted utilization coefficient throughout the shift. It has been established that decreasing the coefficient of excavator utilization throughout the shift and more precise logging of annual work days lead to a slower decrease in estimated machine capacity than the one described in the reference literature. According to the suggested method, estimated excavator capacity is more than 23 % higher than the value stated in the reference literature.

***Key words*:** rock excavation, single-bucket excavator, mechanical shovel, mining equipment maintenance, mining equipment capacity

***How to cite this article*:** Zharikov S.N. Improved Estimation of Open Pit Excavator Capacity. Zapiski Gornogo Instituta. 2018. Vol. 229, p. 56-61. DOI: 10.25515/PMI.2018.1.56

Introduction. Currently the operation of open pit shovel loaders is extensively covered in technical scientific literature. However, following existing guidelines, it is still problematic to calculate excavator capacity for specific sites, and different plants with similar conditions may have estimations that deviate from the average value by factor of 2-2.5. The reasons for that are quite diverse – starting from natural and technological ones and ending with organizational difficulties and personnel qualification [10, 11].

Problem Statement. According to [2], actual excavator capacity is always lower than the maximum possible one due to organizational drawbacks that can only be amended by rational use of operational time, whereas works [1, 4] demonstrate how the efficiency of excavation operations increases with their intensification. It means that excavating equipment has a certain margin of capacity increase, which shrinks with the intensification of mining operations. Hence, it is feasible to understand how this operational time reserve relates to the sufficient minimum principle and how efficiently equipment is used in the particular circumstances. The maintenance of mining equipment is associated with significant costs borne by the company, and in case this equipment is used inefficiently such costs become company's losses. This problem is definitely worth considering, and the first aspect that should be paid attention to is the method of capacity estimation, presented in the reference literature [7]. Let us refer to it as the initial method.

Method and discussion of results. According to [7], operational capacity of a single-bucket excavator can be estimated as follows:

$$Q_e = \frac{3600\,E}{t_c}\,\frac{t_{op}}{t_{op}+t_m}\,\frac{k_b}{k_{fr}}\,k_u\,T_{shift}, \qquad (1)$$

where E – bucket volume, m^3; t_c – cycle duration, s; t_{op} – time of stationary operation, min; t_m – time of equipment movement, min; k_b – bucket fill coefficient; k_{fr} –fragmentation coefficient; k_u – coefficient of time utilization; T_{shift} – shift duration, hr.

According to [7], for truck loading operations coefficient of time utilization amounts to 0.8-0.9. This spread serves as a starting point for a whole range of contradictions associated with further estimation of annual excavator capacity.

Shift operation of mining equipment can be examined in closer detail on the example of excavators EKG-8I and EKG-10. Detailed performance characteristics of these mining machines are described in specification documents [2, 3]. Throughout the shift, time allowances are the following: preparatory operations and machine servicing t_{prep} = 31 min; personal time t_{pers} = 10 min; scheduled

DOI: 10.25515/PMI.2018.1.56

breaks and bulldozer waiting time t_{sched} = 10 min; lunch break t_{lunch} = 30 min; truck waiting time – 0.4 min; truck maneuver time – 0.5-0.7 min. In general, for each truck the loading time is extended by approximately 1 minute. Assuming that the an EKG-10 loads blasted rock mass into a 130-ton truck, the loading time for one machine is 4.0-5.0 minutes, i.e. this addition amounts to 20 % of the total loading time.

In case of continuous truck feed the loading time equals

$$t_{load} = T_{shift} - (t_{prep} + t_{pers} + t_{sched} + t_{lunch} + 0.20 t_{load})$$

or

$$t_{load} = T_{shift} - t_{prep} - t_{pers} - t_{sched} - t_{lunch} - 0.20 t_{load},$$

from which

$$t_{load} + 0.2 t_{load} = T_{shift} - t_{prep} - t_{pers} - t_{sched} - t_{lunch},$$

then

$$t_{load} = \frac{T_{shift} - (t_{prep} + t_{pers} + t_{sched} + t_{lunch})}{1.2}. \quad (2)$$

For an 8-hour shift the loading time equals 5, 6 hours, for a 12-hour shift it is 8, 9 hours. Hence, the coefficient of time utilization in the former case will not exceed 0.7 and in the latter – 0.74. So technologically the coefficient of excavator time utilization for truck loading operations cannot be greater than the above mentioned values. Thus, either the initial method significantly overestimates annual capacity, or overall down time of the equipment make up for the difference, bringing the values to a certain average.

The second ambiguous value in the estimation of excavator capacity is the number of work days per year (on the average, 245 days), which equals 68.5 % of the annual production time. It means that almost a third of the overall time the excavator does not load the rock mass in the trucks. First of all, it can be explained by different types of repairs (preventive overhaul, maintenance, capital and damage repairs). However, repair cycles have different lengths, the interval between some of them is longer than one year, and the logging of repair time which did not take place in the current period eventually leads to mistakes in capacity estimations, so this issue should also be addressed in greater detail.

Below there is an analysis of the duration of repair cycles for excavators EKG-8I and EKG-10 in the light of repair and maintenance data [5, 6, 8, 9]. Statistics from Table 1 served as a basis for establishing a dependence between accumulated repair time of the equipment and machine hours worked between the capital repairs of the mechanical shovel with a 10 m^3 bucket (Fig.1). It can be formulated as follows:

$$t_{rep} \approx 0.2\, t_{cr}^{m}, \quad (3)$$

where t_{rep} – time spent on repair and maintenance after the capital repair of the excavator; t_{cr}^{m} – machine hours worked after the capital repair.

Expression (3) does not take into account time spent on the capital repair itself, but includes the time between two capital repairs in the cycle. Apparently, the time spent on repair and maintenance is directly proportional to the machine hours worked between capital repairs in the full repair cycle. It should be noted that many plants use imported equipment which has a different repair system. In the large companies the number of foreign excavators may exceed the number of EKGs. In the latter case repair systems of domestic machines are usually adjusted to the repair schemes of imported equipment. This way time expenditures are slightly reduced, and the expression (3) may change or have another degree of confidence, but principally the estimation approach stays the same.

DOI: *10.25515/PMI.2018.1.56*

Table 1

Duration of repair cycles between capital repairs of the mechanical shovel with a 10 m^3 truck [6]

Repair type	Time between overhauls, machine hours	Repair time, hours	Machine hours worked by the excavator between two capital repairs	Accumulated repair duration within the repair cycle, hours
I	466	60	466	60
I	466	60	932	120
I	466	60	1398	180
I	466	60	1864	240
I	466	60	2330	300
I	466	60	2796	360
M1	2800	120	2800	480
I	466	60	3266	540
I	466	60	3732	600
I	466	60	4198	660
I	466	60	4664	720
I	466	60	5130	780
I	466	60	5596	840
M2	5600	240	5600	1080
I	466	60	6066	1140
I	466	60	6532	1200
I	466	60	6998	1260
I	466	60	7464	1320
I	466	60	7930	1380
I	466	60	8396	1440
M1	8400	120	8400	1560
I	466	60	8866	1620
I	466	60	9332	1680
I	466	60	9798	1740
I	466	60	10264	1800
I	466	60	10730	1860
I	466	60	11196	1920
M3	11200	336	11200	2256
I	466	60	11666	2316
I	466	60	12132	2376
I	466	60	12598	2436
I	466	60	13064	2496
I	466	60	13530	2556
I	466	60	13996	2616
M1	14000	120	14000	2736
I	466	60	14466	2796
I	466	60	14932	2856
I	466	60	15398	2916
I	466	60	15864	2976
I	466	60	16330	3036
I	466	60	16796	3096
M2	16800	240	16800	3336
I	466	60	17266	3396
I	466	60	17732	3456
I	466	60	18198	3516
I	466	60	18664	3576
I	466	60	19130	3636
I	466	60	19596	3696
M3	19600	336	19600	4032
I	466	60	20066	4092
I	466	60	20532	4152
I	466	60	20998	4212
I	466	60	21464	4272
I	466	60	21930	4332
I	466	60	22396	4392
C	22400	2160	22400	6552

Note. I – maintenance inspection; M1, M2, M3 – maintenance overhaul; C – capital repair.

DOI: 10.25515/PMI.2018.1.56

According to the suggested (second) method, yearly repair time t_{rep}^{y} can be defined as repair duration according to the worked machine hours minus time spent on repairs in the preceding periods:

$$t_{rep}^{y} = t_{rep} - \sum t_{rep}^{ip}, \qquad (4)$$

where t_{rep}^{y} – repair time in the current year; $\sum t_{rep}^{ip}$ – accumulated duration of repairs already performed in preceding periods.

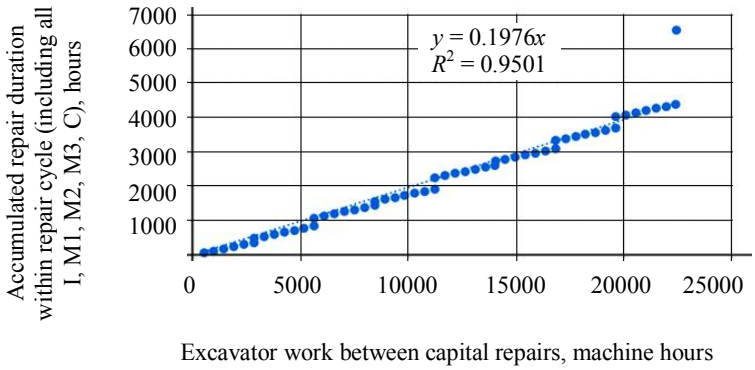


Fig.1. Dependence between accumulated time spent on repair and worked machine hours in the interval between capital repairs of the mechanical shovel with a 10 m^3 bucket

Thus, having planned the amount of machine hours that the equipment has to work in the current year and knowing its production rates in the preceding periods, one can estimate the repair time with a good degree of precision and to specify the number of work days per year.

If there is a capital repair planned for the current year, then its duration is added to the estimated time before and after capital repairs. This can be expressed as follows:

$$t_{rep}^{y} = t_{rep}^{y\text{-}c} + t_{rep}^{c} + t_{rep}^{c\text{-}y}, \qquad (5)$$

where $t_{rep}^{y\text{-}c}$ – part of yearly repair time before the capital repair; t_{rep}^{c} – time of capital repair; $t_{rep}^{c\text{-}y}$ – part of yearly repair time from the capital repair till the end of the year.

Let us consider the suggested method of operational time estimation. According to the plan, the excavator must work 5 000 machine hours per year, in preceding periods it has worked 10 000 machine hours, which means that accumulated repair time in preceding periods amounts to 2 000 hours. Hence, yearly repair time equals 1 000 hours. In case of a 12-hour shift and a 24-hour operation of the plant the excavator down time will be approximately 42 days. The down time must also include a time reserve for emergencies, damage repair and excavator haul – no longer than 20 days. Then excavator operational time throughout the year amounts to 365 – 62 = 303 days.

Here it should be noted that the haulage time can be significantly reduced if the excavator is connected to a diesel generator, placed on the truck following a parallel course with the excavator. This allows the machine to move at a speed higher than 1 km/h, saving up time and increasing effective haulage area.

Attention also should be paid to the estimation of operating excavator park, which depends on the coefficient of excavator reserve

$$k_{res} = \frac{T_y}{n_y}, \qquad (6)$$

where T_y – yearly number of work days for the plant; n_y – yearly number of work days for the excavator.

Let us assume that the nominal excavator park consists of 10 machines. According to the first method k_{res} = 365/245 ≈ 1.49; according to the second one – 365/303 ≈ 1.20. In the former case operational excavator park equals 0/1.49 ≈ 6.71 ≈ 7 machines; in the latter – 10/1.20 ≈ 8.33 ≈ 9 machines. Therefore, even under maximum excavator capacity and high intensity of mining operations underestimation of annual work days results in lower values of the operational excavator park. It can lead to incorrect planning of resources of the repair service as the mining conditions may suddenly demand the introduction of additional machine units.

DOI: 10.25515/PMI.2018.1.56

Table 2

Comparison of the production $k_u n_y$ for two methods of excavator capacity estimation under decreasing k_u

First method			Second method		
k_u	n_y	$k_u n_y$	k_u	n_y	$k_u n_y$
0.90	245	220.5	0.74	303	224.2
0.88	245	215.6	0.73	303	220.1
0.86	245	210.7	0.71	303	216.0
0.84	245	205.8	0.70	303	211.9
0.82	245	200.9	0.69	303	207.7
0.80	245	196.0	0.67	303	203.6
0.78	245	191.1	0.66	303	199.5
0.76	245	186.2	0.64	303	195.4
0.74	245	181.3	0.63	303	191.3
0.72	245	176.4	0.62	303	187.1
0.70	245	171.5	0.60	303	183.0
0.68	245	166.6	0.59	303	178.9
0.66	245	161.7	0.58	303	174.8
0.64	245	156.8	0.56	303	170.6
0.62	245	151.9	0.55	303	166.5
0.60	245	147.0	0.54	303	162.4
0.58	245	142.1	0.52	303	158.3
0.56	245	137.2	0.51	303	154.2
0.54	245	132.3	0.50	303	150.0
0.52	245	127.4	0.48	303	145.9
0.50	245	122.5	0.47	303	141.8
0.48	245	117.6	0.45	303	137.7
0.46	245	112.7	0.44	303	133.6
0.44	245	107.8	0.43	303	129.4
0.42	245	102.9	0.41	303	125.3
0.40	245	98.0	0.40	303	121.2

Two methods need be compared because the first one handles higher coefficient of time utilization and lower number of work days throughout the year, whereas in the second one there is an opposite situation – lower coefficient and greater number of work days. The most convenient way to carry out the comparison is the following. Let us assume that Q_e part of the expression (1) is constant:

$$\frac{3600\,E}{t_c}\,\frac{t_{op}}{t_{op}+t_m}\,\frac{k_u}{k_{fr}}\,T_{shift} = \text{const} \qquad (7)$$

Then capacity variation can be explained by changes in the production of coefficient of time utilization and the number of work days throughout the year ($k_u n_y$). For maximum k_u values results for both methods are the following: according to the first one, $k_u n_y = 0.9 \cdot 245 = 220.50$; to the second one – $k_u n_y = 0.74 \cdot 303 = 224.22$.

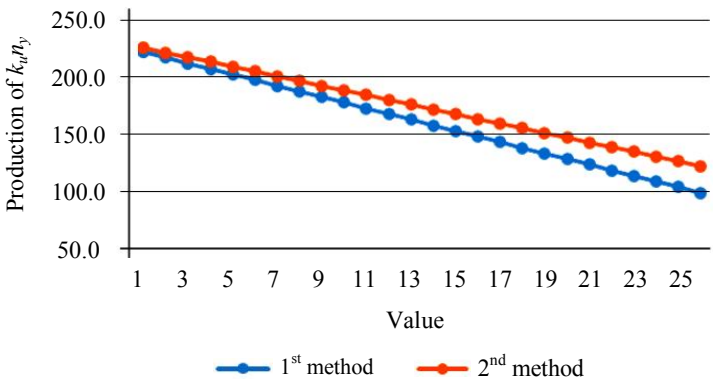


Fig.2. Graphs of $k_u n_y$ variations calculated for both methods under k_u value decreasing till 0.4

The difference is only 1.7 %, which does not exceed permissible estimation error. However, those are results for the maximum k_u, which makes them more of ideal values. That is why the dynamics of $k_u n_y$ production should be analyzed under k_u value decreasing till 0.4. Corresponding results are presented in Table 2 and Fig.2. Intermediate values have been obtained by means of interpolation, the total of 26 values has been selected.

DOI: *10.25515/PMI.2018.1.56*

According to the graphs, the first method demonstrates greater decrease of estimated capacity from the initial value (55.56 %), as compared to the second method (45.95 %). The difference in capacity under $k_u = 0.4$ is 23.67 % from result of the first method.

Conclusion. The analysis of capacity estimation of a single-bucket excavator demonstrates that for truck loading operations the coefficient of time utilization is lower than the values described in reference literature. Maximum values of $k_u \leq 0.74$.

A method has been suggested on how to calculate the annual number of excavator work days taking into account repair cycle and adjusted coefficient of excavator utilization throughout the shift.

It has been demonstrated that repair time logging within the full repair cycle results in higher values of work days in the estimation of equipment capacity, which can lead to greater annual capacity of the excavator provided the relevant organization of mining operations. This is possible if the mining operations reach a certain level of intensity, as constant loading of the rock mass should be supported by a relatively high rate of preparatory operations.

Comparing the coefficients of excavator reserve based on the number of work days calculated with two described methods, the author demonstrates how underestimation of annual work days results in a lower number of operational excavator park.

It has been established that decreasing the coefficient of excavator utilization throughout the shift and more precise logging of annual work days leads to a slower decrease in estimated machine capacity than the one described in the reference literature. According to the suggested method, under $k_u = 0.4$ estimated excavator capacity is more than 23 % higher than the value stated in the reference literature.

REFERENCES

1. Gryaznov M.V., Kolobanov S.V. Capacity Resources of Excavating and Transportation Equipment. *Mir transporta*. 2013. N 3, p. 96-102 (in Russian).

2. Unified Standards of Performance and Time for Rock Mass Excavation and Truck Transportation at Non-Ferrous Metallurgy Plants. Mintsvetmet SSSR. Moscow, 1986, p. 92 (in Russian).

3. Unified Standards of Performance for Open Pit Operations at Mining Plants. Part IV. Rock Mass Excavation and Truck Transportation. Tsentral'noe byuro normativov po trudu. Moscow, 1989, p. 81 (in Russian).

4. Zharikov S.N. Energy Expenditures of Rock Mass Excavation and Coordination of Resources Extraction with Adjacent Mining Operations. *Fundamental'nye i prikladnye voprosy gornykh nauk*. 2017. Vol. 4. N 1, p. 179-186 (in Russian).

5. Operational Guidelines 3519.00.00.000 Excavators EKG-8I, EKG-6,3 and EKG-4U. PO «Izhorskii zavod» im. A.A.Zhdanova. Leningrad, 1980. URL: http //www.studmed.ru/view/ instruktsiya-po-ekspluatatsii-ekskavatorov-ekg-8i-ekg-6zus-i-ekg-4u_6b7ab63a32d.html (date of access 23.01.2017) (in Russian).

6. Mel'nikov N.V. Quick Reference Book on Open Pit Mining Operations. Moscow: Nedra, 1968, p. 308 (in Russian).

7. Trubetskoi K.N., Potapov M.G., Vinitskii K.E. et al. Open Pit Mining. Moscow: Gornoe byuro, 1994, p. 590 (in Russian).

8. Decree of USSR State Committee for Labour, All-Union Central Soviet of Trade Unions Secretariat from 23.07.1985 No. 235/16-21. On the Adoption of Time Standards for the Repair of Mechanical Shovel Excavators EKG-8, EKG-8I. URL: http://bestpravo.ru (date of access 19.02.2016).

9. Operational Guidelines 3536.00.00.000RE Open Pit Caterpillar Excavators EKG-10, EKG-8US and EKG-5U. OAO «Izhorskie zavody». St. Petersburg, 2000. URL: https://www.twirpx.com/file/615105// (date of access 23.01.2017).

10. Baskakov V.P., Borzykh E.V., Zhivotyagin A.M. et al. Standardization of Production Operations as a Key Trend of Plant and Company Development. Moscow: Gornaya kniga, 2010, p. 46 (in Russian). (Seriya «Biblioteka gornogo inzhenera rukovoditelya». Iss. 4).

11. Khokhryakov V.S. Open Pit Development of Mining Fields. 5-e izd., pererab. i dop. Moscow: Nedra, 1991, p. 336 (in Russian).

Author **Sergey N. Zharikov,** *Candidate of Engineering Sciences*, *Senior Researcher*, *333vista@mail.ru* (*Institute of Mining, Ural branch of RAS, Yekaterinburg, Russia*).

The paper was accepted for publication on 7 July, 2017.