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BASIC MODEL OF EXCAVATOR AND LOADER OPERATION USING COMPUTER SIMULATION

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Abstract: The regularities of changing both the capacity and prime cost of an excavator-truck set are correlated together with the growth of the excavator's bucket capacity and the number of trucks, serving one excavator. The results of computer simulation us ing specialized software developed in the IM UB RAS are presented as well as different variants of common excavator-truck sets. Technical and eco nomic calculations in terms of simulation results and estimation the cost of ETS ownership for 7 years are performed. The principles of selection EAS parameters are formulated.

Key words: excavator-truck set, computer simula tion, open pit transport system, ownership cost, technical and economic indices.

A large number of works have been devoted to the issues of justifying the productivity of excavator-dump truck complexes (EDC) in quarries, which is associated with the determining role of this equipment in the cost of mineral extraction, the rate of development of mining operations, etc. The solution of problems in this area is required in two aspects:

- theoretical research related to the search for rational structures for organizing work, optimal parameters of mining and transport machines, research into the development of quarry transport systems, etc.;
- applied calculations for determining the types, models and quantities of mining equipment when designing quarries or their technical re-equipment.

One of the important issues is the correct selection of excavator-truck complexes based on a set of interrelated factors: the ratio of the capacity of the excavator bucket and the dump truck body (weight and volume modules of the EAC according to A.A. Kuleshov [1]), the number of dump trucks servicing the excavator, and their lifting capacity. The solution to this problem has been considered by many authors from different aspects.

Thus, in the work of Vasiliev M.V., Sirotkin Z.L., Smirnov V.P. [2] a solution is presented using methods of queuing theory to the problem of selecting a rational combination of loading and transport equipment based on the productivity of an excavator depending on the number of dump trucks servicing a given excavator. The authors have shown that with a small number of dump trucks on the road, their utilization rate is close to one, and the excavator productivity increases according to a straight-line law. As the number of dump trucks increases, the rate of increase in their productivity decreases, and in the case of the system being completely saturated with dump trucks, productivity growth stops completely (Fig. 1). It is clear from the figure that the range of productivity variations (shaded area) is quite wide and depends on a number of additional work organization factors. According to [2, p. 224], the highest excavator productivity can be achieved when the production line is completely saturated with vehicles. It should be noted that it is important to evaluate not only technological but also technical and economic indicators, which may influence the choice of a rational option. Thus, the most economical option will most likely correspond to a line that is not fully saturated with dump trucks.

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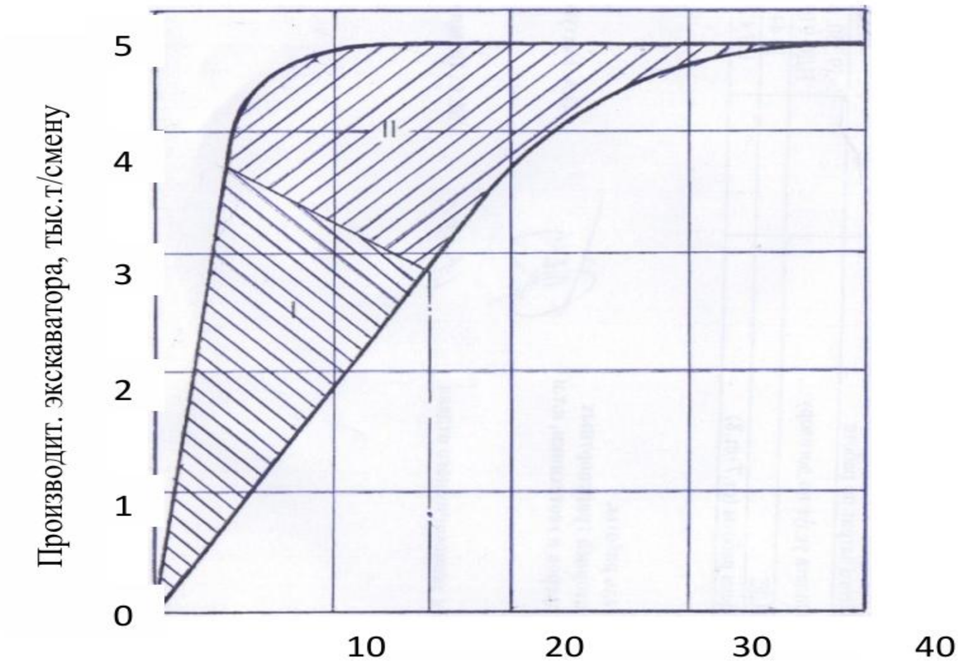

Number of excavators, pcs.

Fig. 1 – Productivity of the EKG-4 excavator depending on the number of BelAZ-540 dump trucks servicing it, according to data from [2, p. 224]

In the work of A.A. Kuleshov [3], calculations of the specific costs for excavation and transportation of rock mass by the EAC are presented depending on the weight and volume module of the complex, reflecting the presence of a minimum of specific costs depending on the ratio of the volume of the excavator bucket and the capacity of the cargo platform of the dump truck (Fig. 2).

In the work of A.A. Kuleshov [3], calculations of the specific costs for excavation and transportation of rock mass by the EAC are presented depending on the weight and volume module of the complex, reflecting the presence of a minimum of specific costs depending on the ratio of the volume of the excavator bucket and the capacity of the cargo platform of the dump truck (Fig. 2). The solution to this problem is possible on the basis of computer modeling in the program “Quarry Transport System” (QTS), developed at the Institute of Mining of the Ural Branch of the Russian Academy of Sciences [4]. This allows, on the one hand, to solve problems that arise when solving a problem using methods of queuing theory (errors), and on the other hand, to bring the operating mode of the EAC as close as possible to a real quarry by modeling the systematic and random downtime that arises, changes in the duration of excavation and transportation processes.

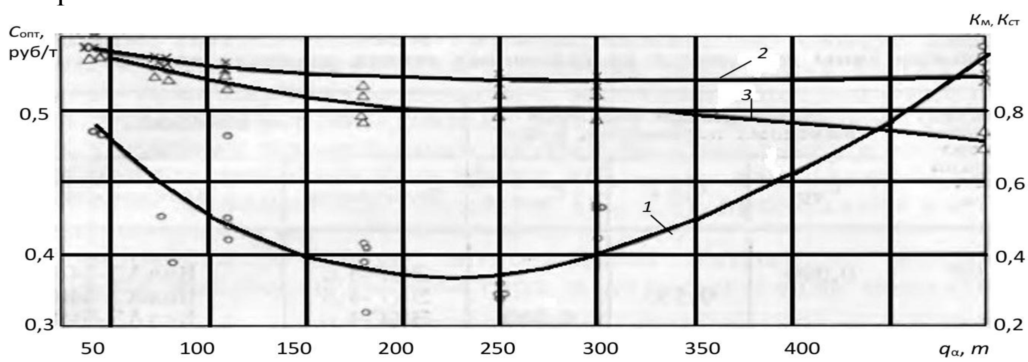

Fig. 2 – Dependence of specific reduced costs for EAC on the carrying capacity of dump trucks [3, p. 293]:
1 – specific reduced costs for EAC,
2 – maneuverability coefficients Km of the complex,
3 – stability coefficient of EAC

The algorithm of the TSC program operation consists of a step-by-step (with a time step of 1 s and smaller) reproduction of the operation of excavation and loading equipment, transport vehicles, and transfer points as part of a spatial model of the quarry transport system specified in the database (including roads, loading and unloading areas). The model can contain up to three simultaneously simulated modes of transport (automobile, rail, conveyor), each of which operates according to separate algorithms and within the framework of a separate transport communications scheme, connected, if necessary, by transfer points.

The TSC program allows simulating various options for the operation of a quarry transport system, using the required types of quarry transport (excavators, dump trucks), on a real traffic pattern. After modeling, you can select the optimal combination of excavators and dump trucks and use this combination in a real quarry for maximum efficiency. The TSC program is applicable for:

– identifying bottlenecks in the transport system design;

– selecting mining and transport equipment parameters by comparing the results of modeling different equipment combinations and models;

- optimization of technological process management for mining and transport operations;

- long-term forecasting of rational options for developing quarry transport systems.

Conditions for carrying out calculations: for all the considered EACs, the same calculation route was adopted with a ring movement between one loading and one unloading (Fig. 3). The length of the route from loading to unloading is 7 km. The volume of transported rock mass was determined based on the maximum possible productivity of the complex, based on the results of computer simulation modeling. Based on the results of the modeling, the technological indicators of each complex were determined: the volume of rock mass actually transported, the mileage of the dump truck fleet, fuel consumption, etc. The volume of rock mass loaded by the excavator is obviously equal to the volume of rock mass transported.

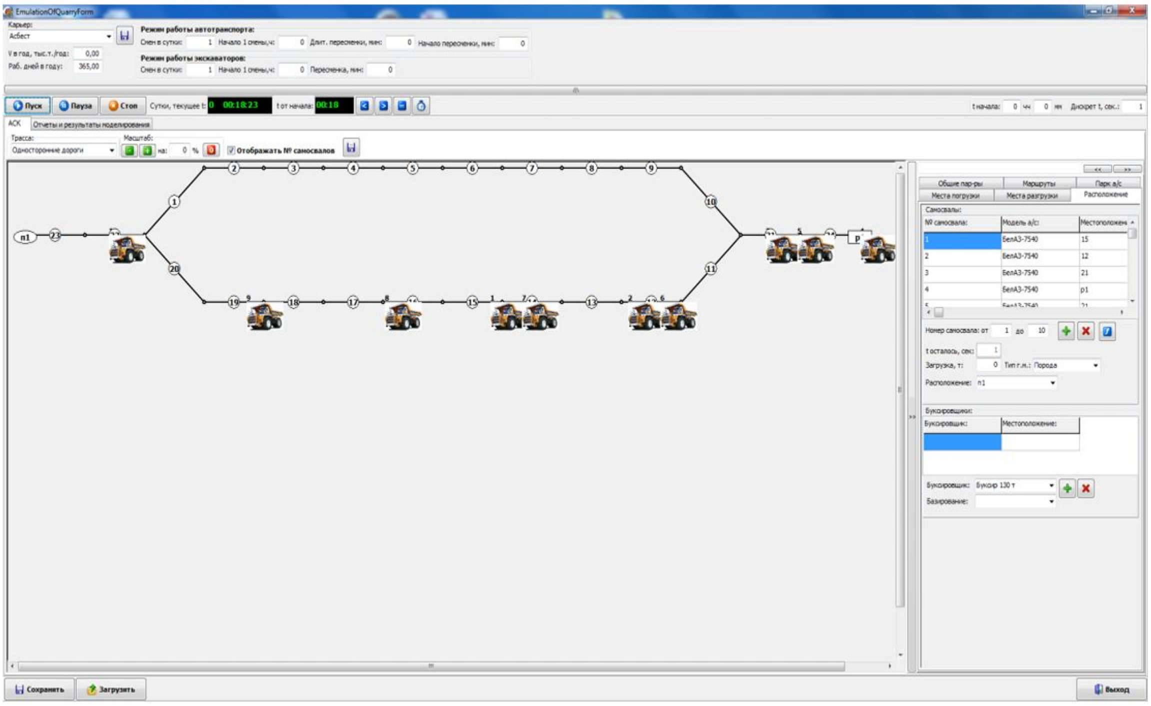

Fig. 3 – TSK simulation window with a ring route

The comparison was conducted for several simple excavator-dump truck systems (Table 1). For each excavator and dump truck model combination, several sub-variants with different numbers of dump trucks in the system were considered.

Table 1

Compared excavator-truck combinations

Параметр	Вариант ЭАК*									
	ЭКГ-5 (7540)	ЭКГ-8 (7540)	ЭКГ-20 (7540)	ЭКГ-5 (7555)	ЭКГ-8 (7555)	ЭКГ-20 (7555)	ЭКГ-8 (7513)	ЭКГ-15 (7513)	ЭКГ-20 (7513)	ЭКГ-40 (7513)
Весовой модуль ЭАК (с учетом коэф. заполнения ковша и разрыхления)	3,6	2,3	2,3	6,6	4,1	1,7	10,2	5,4	4,1	2,0
Объемный модуль ЭАК	3,8	2,4	1,0	6,6	4,1	1,7	8,8	4,7	3,5	1,8
Подварианты по количеству автосамосвалов (ед.)	5	5	5	5	5	5	5	5	5	5
	10	10	10	10	10	10	10	10	10	10
	15	15	15	15	15	15	15	15	15	15
	20	20	20	20	20	20	20	20	20	20

The model of BelAZ dump trucks is given in brackets.

The simulation was conducted for the duration of one 8-hour shift for all variants. Then, taking into account the annual working time fund for a year-round 3-shift operation, the annual productivity of each EAC was calculated and is presented in Fig. 4. From the graph (Fig. 4) it is evident that for all variants at the level of 10–15 dump trucks operating on the line, saturation of the transport system has been reached, when productivity practically does not increase with the

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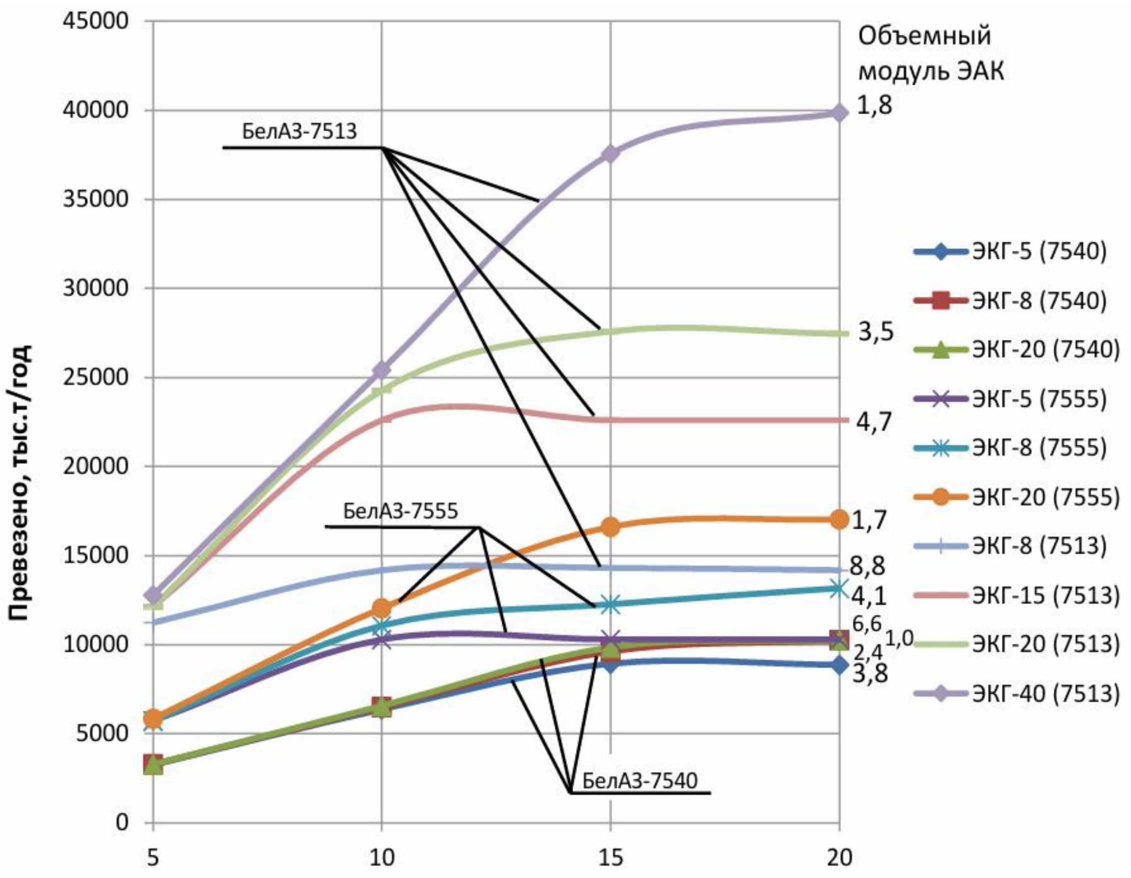
increase in the fleet of transport vehicles. In this case, saturation occurs earlier, the larger the weight (volume) modulus of the EAC. Also, certain regularities are observed: with an increase in the lifting capacity of dump trucks, the productivity of the complex increases significantly, however, in the case of using excavators with a small bucket capacity with a volumetric module of the EAC of more than 6.5 – 7.0, the productivity of the complex is even lower. than the EAK with lower-capacity dump trucks, but with a larger excavator bucket (see EKG 8 (7513) and EKG-20 (7555)). At the same time, when working in tandem with an excavator, the bucket capacity of which is close to the optimal for a given dump truck (according to the recommendations of many literary sources: The combination of 4-6 excavator buckets per truck load significantly increases the productivity of the EAC. For example, 15 BelAZ-7513 dump trucks paired with an EKG-40 excavator provide 26.5% higher productivity than the combination with an EKG-20, while 20 such trucks provide 32% higher productivity.



Number of dump trucks, units
Fig. 4 – Estimated annual productivity for the considered EACs

From a productivity standpoint, it's rational to choose an excavator with a weight (volume) module of less than 4. However, larger excavators entail increased capital and operating costs. Therefore, it's important to evaluate the technical and economic performance of the options considered.

The technical and economic calculation is based on the technological parameters and cost indicators obtained through modeling, determined both by analogs and existing prices for consumables, and on regression dependencies similar to the method described in [5]. For dump trucks, research data [5, 6] were used. For excavators, regression relationships were established

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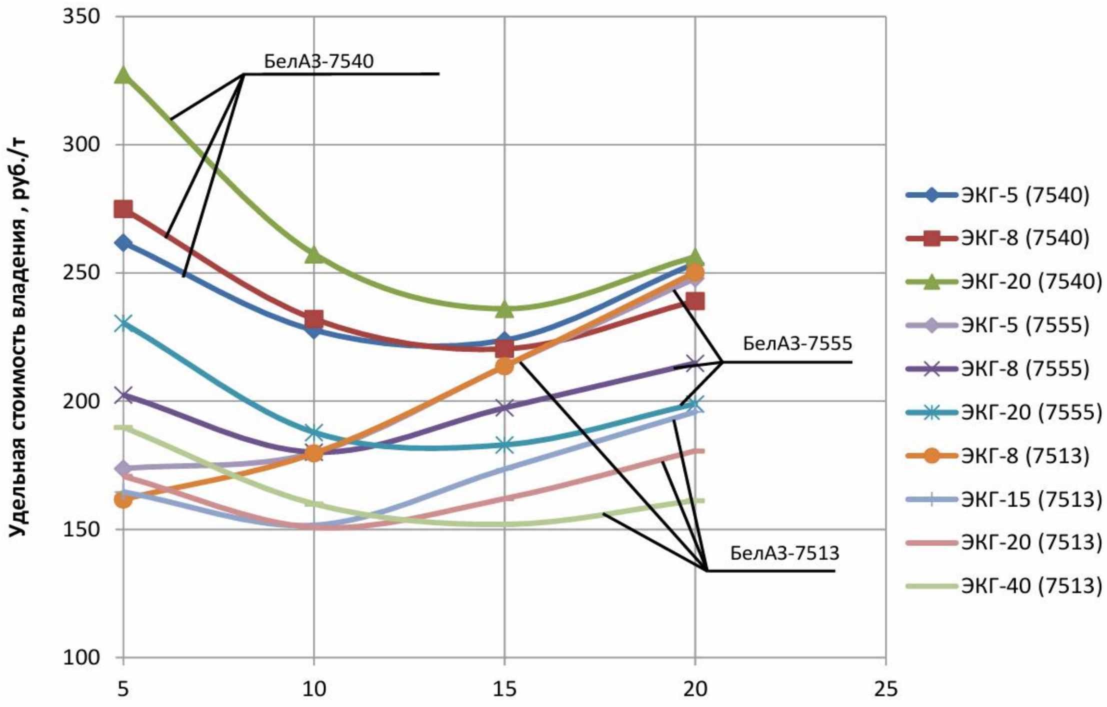
based on cost data [7, 8] and, by extrapolation and interpolation, the desired specific economic indicators of excavation were determined depending on the capacity of the excavator bucket.

To establish general patterns without reference to a specific investment project for a specific mining enterprise, it is convenient to use the "cost of ownership" indicator, calculated as the sum of capital and operating costs over a fixed period of time (usually the service life of the equipment). For the calculations in this article, a period of 7 years is adopted (the average service life of quarry dump trucks).

Figure 5 shows that the lowest costs are achieved with more productive equipment. The most cost-effective option must be selected based on a combination of factors: for the same dump truck model, with low transportation volumes and a small number of trucks, the option with a smaller excavator will be preferable, while with increasing transportation volumes, the option with a more productive excavator will be preferable. It is also clear that using excavators that are too small (with a weight (volume) module of the EAC greater than 8) leads to a sharp increase in costs (see EKG-5(7555) and EKG-8(7513)).



Number of dump trucks, units.

Fig. 5 – Specific cost of ownership of the EAC over 7 years, reduced to 1 ton of transported rock mass

The development of the EAC has been extensively researched. For example, A.A. Kuleshov [3] provides calculations of the specific costs of excavating and transporting rock mass with the EAC for various weight and volume modules of the system, reflecting the existence of a minimum specific cost depending on the ratio of the excavator bucket capacity to the dump truck cargo bed. The calculations presented in this article show that in most cases there is also an optimum in the specific cost per ton of transported rock mass depending on the number of trucks servicing the excavator. The optimum position depends on both the excavator bucket capacity and the truck load capacity.

This fact and the data in Figure 5 allow us to formulate an additional methodological principle for selecting the parameters of the EAC: for EAC variants with similar or identical technical and economic indicators and a greater number of dump trucks servicing the excavator,

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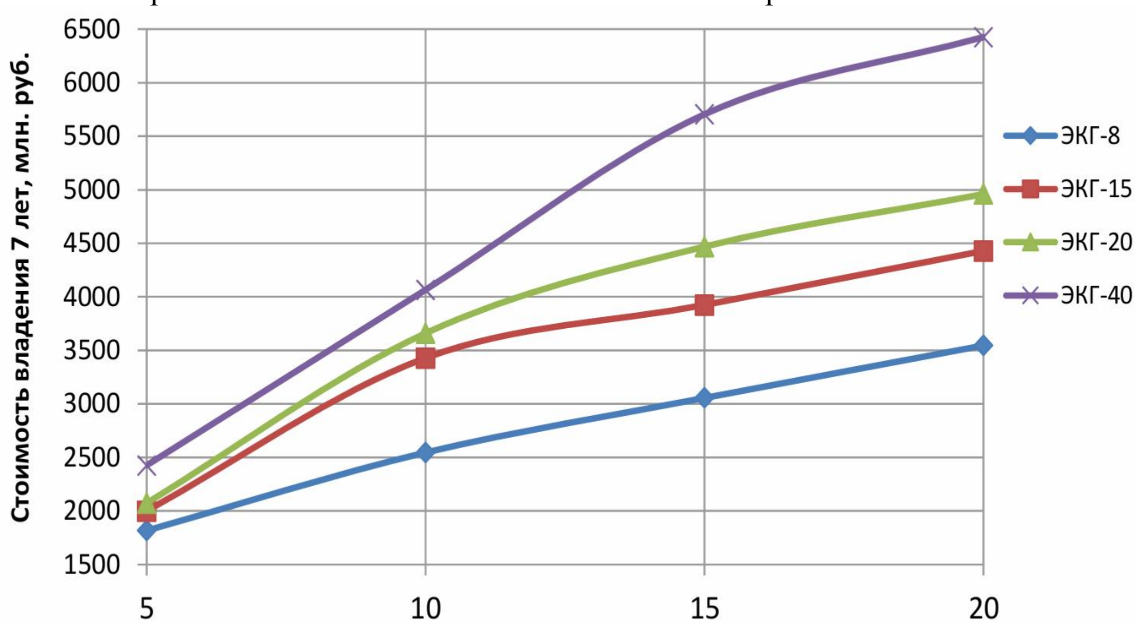
preference should be given to excavators with a larger bucket capacity (or, equivalently, smaller values of the weight and volume modulus of the EAC should be adopted), and for variants with a smaller number of dump trucks in the EAC, preference should be given to excavators with a smaller bucket capacity (larger values of the weight and volume modulus of the EAC). It should be taken into account that the minimum specific costs do not always correspond to the minimum absolute cost indicators. Thus, Figure 6 shows the total costs over 7 years for the operation of a simple EAC with BelAZ-7513 dump trucks. It's clear that the cheapest option in terms of unit costs (see Fig. 5) with an EKG-40 excavator is, in absolute terms, the most capital-intensive. Therefore, if a company cannot afford to invest large sums in a powerful system, it should choose the most rational option with smaller excavators, for example: an EKG-20 excavator with 12 BelAZ-7513 dump trucks or an EKG-15 with 9 BelAZ-7513 dump trucks.



Number of dump trucks, units.

Fig. 6 – Total cost of ownership of an excavator-truck system versus the number of trucks (an excavator-truck system consists of one excavator and BelAZ-7513 dump trucks)

These studies allow us to draw the following conclusions.

1. The existing methodological framework for selecting the parameters and composition of excavator-truck systems requires clarification, taking into account the implementation of computer simulation methods for excavator-truck systems.
2. An important issue when selecting excavator-truck system parameters, along with the optimal combination of excavator bucket capacity and truck body capacity, is the selection of the number and lifting capacity of the trucks servicing the excavator. The most cost-effective option depends on the transportation route parameters and the required excavator-truck system performance.
3. The minimum cost of excavating and transporting rock mass using an excavator-truck complex with varying numbers of trucks on the line is determined by the saturation point of the transport system with trucks (when the productivity of the complex practically does not increase with an increase in their number).
4. For EAC variants with similar or identical technical and economic indicators and a larger number of trucks servicing the excavator, preference should be given to excavators with a larger bucket capacity (or, equivalently, to adopt smaller values of the EAC weight and volume modulus), and for variants with a smaller number of trucks in the EAC, preference should be

given to excavators with a smaller bucket capacity (larger values of the EAC weight and volume modulus).

5. The growth of the EAC productivity slows down significantly when the values of the EAC volumetric modulus reach 2.5, and when the values of 1.8–2.0 are reached, the productivity does not increase.

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