UDC 622.271:622.693 DOI: https://doi.org/10.15407/geotm2025.173.101

THE FEASIBILITY OF INTRODUCING ARTICULATED AND TRACKED DUMP TRUCKS AT NON-METALLIC QUARRIES

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Abstract. The purpose of the publication is to determine the feasibility of using different types of dump trucks in non-metallic quarries, considering the transport distances, trip duration, and productivity when transporting rock mass from the mines to the surface. To achieve this goal, the following research methods were used: analysis of modern quarry transport, analytical - to establish the parameters of the trip duration and dump truck productivity, graphical - to find the optimal type of dump truck, operational monitoring - to establish the time parameters of mining equipment operation. A review of the modern usage of dump trucks in the development of non-metallic quarries is carried out, which allowed us to distinguish dump trucks with a 4×2 wheel formula, articulated and tracked. An analysis of vehicle operation in different conditions was carried out. This made it possible to justify the parameters of vehicle operation and identify the factors affecting the performance of dump trucks. The results of the study are the determination of the dependence of the length of the route and the duration of the dump truck trip on the depth of the non-metallic mine pit face, as well as the productivity of the relevant machines. For crawler dump trucks, the parameters of dump truck operation and the formula for determining the approach time to the face for loading with rock mass and unloading at the appropriate site were established. The received dependence of the dump truck's approach allows us to determine the productivity of the crawler machine, taking into account the use of a full-rotating platform (the cab and body are on a single rotating base), which eliminates operations related to manoeuvring on the work site and increases the productivity of such machines. The research showed that transporting raw materials from the quarry using tracked dump trucks, thanks to the shorter transport distance, requires almost 40% less transport work (tonne-kilometres) than when using wheeled quarry dump trucks. The length of the route when using transport vehicles was determined, considering the increase in the road gradient for crawler dump trucks. The scientific novelty of the research results is to determine the dependence of the route length and the duration of the dump truck trip during deepening of the mining operations.

Keywords: rock mass transportation, quarry, wheeled dump trucks, articulated dump trucks, dump truck trip duration, dump truck productivity

1. Introduction

The dominant trend in developing non-metallic deposits in the mining industry, including in Ukraine, is the open method. Accordingly, its share reaches 73% of mineral resources in the world. The largest expense in open-pit mining is the cost of moving rock mass from the mine workings to unloading sites, which can reach 60–70% of the total costs. In this case, mining transportation development and further improvement is essential for open mining [1]. At the current stage of development of equipment and technologies, mobile devices and machines equipped with internal combustion engines (mostly diesel) are increasingly used for mining operations. This includes mining dump trucks. This equipment has several advantages, including mobility, unification and versatility, independence from the power grid, and safer operating conditions. The disadvantages of this equipment are the high fuel and lubricant costs [2] and the energy consumption of these machines [3].

Dump trucks are the most common transport at non-metallic quarries in Ukraine. Dump trucks with a 4×2 wheel arrangement and a carrying capacity of 30...40 tons are the most common. Some quarries use other dump truck models, but not in significant amounts. These are articulated and tracked dump trucks manufactured by many foreign companies, such as Volvo, Caterpillar, BeLAZ, Bell, Komatsu, Terex, and others (Fig. 1).

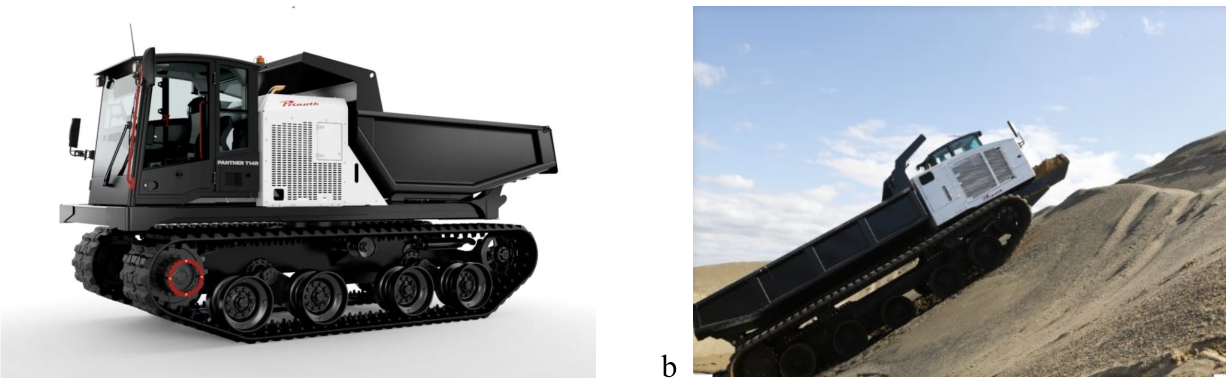
Received: 07.04.2025 Accepted: 09.06.2025 Available online: 20.06.2025

Figure 1 – Volvo articulated dump truck Volvo

These dump trucks are widely used in non-metallic quarries in England for limestone mining (Tarmac Pant Quarry), plastic depths (WBB Minerals), and in Italy for marble mining (Marmi di Carrara Srl) [4]. In Ukraine, articulated dump trucks are successfully used at the quarries of Vesco, Novoselivskyi MPP (MPP – Mining and processing plant), and others. They have confirmed the ability to overcome significant road gradients (up to 35%), work in mountainous terrain without road surfaces, and ensure safe transportation and driving conditions for dump trucks.

The positive qualities of an articulated dump truck include good mobility and a relatively small turning radius. The negative ones include a decrease in stability in difficult operating conditions, a prohibition on reversing on road gradients (more than 8–10%) based on safety conditions.

The study considers alternative dump trucks that are not yet widely used in non-metallic quarries in Ukraine. Crawler dump trucks (CDTs) are not widely used in Ukrainian quarries, which is primarily due to the low load capacity of crawler dump trucks, which currently ranges from 10–20 tons and a speed of 12–20 km per hour, and the lack of awareness among the mining community. Tracked dump trucks are manufactured by Mitsubishi, Komatsu, Morooka and others. Italy produces Panther T-14 and Panther T-16 tracked vehicles (Fig. 2), which are successfully used in marble quarries [5, 6].



a b

Figure 2 – Crawler dump truck Panther T-14 (a) Panther T-16 (b) [5]

A special feature of the crawler dump truck, along with its design solutions, is the ability to work in various conditions, including at a water level of up to 1.4 m, which makes it possible to use them for the extraction of sand and grain from rivers and the dumping of protective shafts made of blocks on water bodies (lakes, rivers).

They successfully work on road construction in areas with low soil bearing capacity and mountainous terrain and can overcome a road gradient of up to 45%.

The Morooka MST-1000VDR crawler dump truck with a 20-ton capacity and a speed of 12 km per hour and a full-tilt platform is particularly interesting. The full rotation of the dump truck platform (body with operator's cab) allows the dump truck to approach for loading and unloading without additional maneuvers, thus reducing the time needed for the transportation cycle and for preparing turning areas, which reduces the width of the working area.

It should be mentioned that crawler dump trucks have recently become more widely used in mining, road construction, forestry, and other industries [7]. Such machines have proven themselves in the development of deep quarries in South America, Africa and other regions of the world where difficult conditions prevail. At the same time, they are used in the open mining of shallow and upland quarries abroad and can be implemented in Ukraine in the formation of non-metallic quarries that produce chemical and metallurgical raw materials, construction minerals, refractory and bentonite clays.

Despite several advantages, these machines have disadvantages, including relatively low load capacity of the crawler; low speed of movement; low resource of rubber-metal tracks (up to 1000 engine hours) for $9000.

The ability to overcome high road gradients and work in compressed conditions, taking into account the size of the crawler dump trucks, leads to a reduction in transportation areas and an increase in the angle of the quarry's idle side. In this regard, they can be used as the main transport in the development of upland deposits in the Carpathians (such as Trybushany, Rokosovo, Novoselivskyi quarry, etc.), pebble mining in the Stryi River, etc.

Particular attention should be paid to the choice of vehicles for excavation and loading operations. The usage of vehicles together with excavators of various types is described in references [8–9]. The main disadvantages of using draglines are that the bucket sways when unloading into the body and requires a highly skilled driver. Therefore, hydraulic excavators with a bucket capacity of 1.5 to 3.5 m^3 are required when articulated and tracked dump trucks are used.

The development of overburden workings and the formation of roads at operating non-metallic quarries allows us to identify the peculiarities of the influence of the components of the overburden workings route on the transportation distance when using road transport in quarries, as proven in [10–11]. The implementation of steep trenches with a road gradient of 20–45% allows for a 10–25% reduction in transportation distance along an inclined quarry route within the range of road gradient changes from 10 to 35% and further increases in road gradient do not significantly affect transportation distance. When defining the length of transportation and using steeply inclined road gradients, it should be taken into account that the size of the route elongation factor should increase with the increase in the road gradient. In turn, the transportation distance affects the time required to transport the rock mass from the pit to the reprocessing facilities.

This is an essential problem, and the solution will allow us to establish the possibility of using and the feasibility of introducing articulated and tracked dump trucks in non-metallic quarries and determine the efficiency of vehicles.

2. Methods

Given the above, the study aims to compare the transport distances and determine the trip duration when using different types of vehicles (wheeled and tracked dump trucks), which will directly affect their performance in rock mass transportation in the quarry.

3. Theoretical and experimental parts

To assess the feasibility of using a dump truck model for transporting rock mass in a particular quarry, it is necessary to consider how the transportation distance and the duration of the transport cycle change, and how the use of a specific type of dump truck will depend on the characteristics of the quarry itself.

Considering the design features of articulated and tracked dump trucks, it is necessary to consider the components of the transport cycle of each machine, for example, when transporting minerals to a crushing and grading plant of a granite quarry. As it is known, the transport cycle consists of loading dump trucks in the mine workings by an excavator; moving vehicles to the unloading point (in our case, the crusher bunker); unloading dump trucks; moving empty dump trucks to the quarry.

The time spent on transportation can be determined by the well-known formula [12]:

$$T_p = t_l + \frac{l}{V_l} + t_u + \frac{l}{V_u} + t_{ml} + t_{mu}\text{, min} \tag{1}$$

where $t_н$ – dump truck loading time, min; l – transportation distance, km; t_l – time of unloading the dump truck, min; V_l, V_u – speed of movement of loaded and empty dump trucks, km/min; t_{ml}, t_{mu} – the period of dump truck manoeuvres during loading and unloading, min.

The transport distance consists of the individual components of the route and the transportation through the trench, along the temporary road in the quarry, and on the surface from the trench to the unloading point:

$$l = \sum_{from 1}^{n} l_j\text{, km} \tag{2}$$

where l_j – the length of the j-th section of the route, km.

In general, the formula for determining the transportation distance is as follows:

$$l = l_m + \frac{1000 \cdot H}{i} K_m + l_n \text{, m} \qquad (3)$$

where l_m – length of transportation in the quarry, m; H – pit depth, m; i – trench gradient, ‰; K_m – track development factor; l_n – length of transportation on the surface, m.

As can be seen from the graph (Fig. 3), the transportation distance varies significantly for different dump truck models, from 700 m for tracked dump trucks to almost 2000m for the BelAZ-7510.

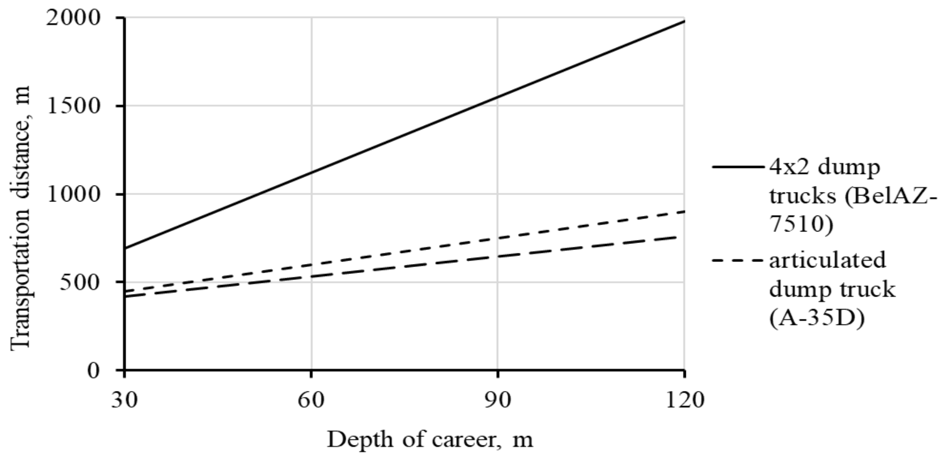


Figure 3 – Graph of changes in transport length depending on the depth of the pits

In our case, the length of the trench transport depends on the depth of the quarry and the road gradient that our dump trucks have to overcome. The distance of transport along the temporary road in the quarry is on average 200 metres, and the distance from the trenches to the bunker is 100 metres.

The resulting distances make it possible to calculate the time required to move the dump trucks and to calculate the time spent on the transport cycle.

In this case, while analysing the cycle components, we are mainly interested in two components: loading time and unloading time, which will be affected by the design features of the dump trucks. The loading time of a dump truck will depend on the organisation of transport in the excavator face: the layout of dump trucks for loading, the width of the working area, which provides the necessary manoeuvre patterns for installing machines under the excavator, etc. The unloading time will also depend on the design of the dump truck. The loading time for dump trucks depends on the load capacity and capacity of the dump truck, the bucket capacity of the excavator and the characteristics of the rock. It can be set by the formula:

$$t_l = t_c \cdot n_k + t_r \text{, min} \qquad (4)$$

where t_c – excavator cycle time during loading of rock mass into a dump truck, min;

n_k – the number of excavator buckets loaded into the dump truck body, units; t_r – time of approach and manoeuvres during installation for loading, min.

The approach time primarily depends on the distance where the dump truck is waiting to be loaded and the design of the 4x2 wheeled dump truck, or articulated dump truck, or tracked dump truck. It should be noted that a 4x2 wheeled vehicle and articulated dump truck must perform reversing manoeuvres for loading and unloading and drive the distance from the waiting area to the loading area, while a crawler dump truck only covers the distance from the parking area. The time for the arrival of the tracked dumper can be determined by the formula:

$$t_{rT} = \frac{R(0.5\pi + 1) + 2 \cdot l_m}{V_m} + t_{nn} \cdot (n-1), \text{ min} \tag{5}$$

Time for a tracked dump truck to arrive

$$t_{rTL} = \frac{S_m + l_m}{V_m}, \text{ min} \tag{6}$$

where R – the turning radius of the dump truck, m; l_m – overall machine length, m; V_m – speed of dump trucks during manoeuvres at loading and unloading areas, m/min; t_{nn} – time for gear shifting, min; n – number of changes in movement directions, units; S_m – safe distance between dump trucks on the site, m.

"Loading time" consists of the sum of the excavator loading time and the time of manoeuvres during loading, as well as "unloading time". The source data are shown in Table 1.

Table 1 – Source data for time calculation loading and unloading time

Indicators	Dump trucks			
	Articulated dump truck A35D	Tracked dump trucks 30	Morooka	BelAZ 7510
Load capacity Q_a, T	37.5	30.0	20.0	30.0
Turning radius of the dump truck R, m	8.72	-	-	8.3
Overall length of the machine, mm	11200.0	8300.0	7200.0	7250.0
Dump truck speed, km/h	50.0	10.0	12.0	50.0
Safe distance between machines, m	12.0	12.0	10.0	10.0

The loading time for dump trucks depends on factors such as physical and mechanical characteristics of the rock, rock looseness, mining parameters, excavator type, bucket capacity, work organisation, etc.

The loading time can be set:

$$t_l = t_c \cdot n_k, \text{ min} \tag{7}$$

where t_c – excavator cycle time, min; n_k – the number of buckets that can fit in the body, units;

$$n_k = \frac{Q_a \cdot k_p}{E_e \cdot k_н \cdot \gamma}, \text{ units} \quad (8)$$

where Q_a – dump truck capacity, t; E_e – excavator bucket capacity, m^3; k_p – the ratio of rock mass loosening in the excavator bucket; $k_н$ – excavator bucket filling ratio; γ – rock density, t/m^3.

Table 2 shows the source data for calculating the loading time of dump trucks. The components of the transport cycle are shown in Table 3.

Table 2 – Source data for calculating the loading time of dump trucks

Q_a, t	E_e, m^3	k_p	$k_н$	γ, t/m^3
See Table 1	4.0	1.6	1.5	2.65

Table 3 – Transport cycle components

Components	Dump trucks			
	BelAZ 7510	A35D	Tracked dump trucks -30	Tracked dump trucks -20
Access to the excavator (bunker), min	0.35	0.67	0.36	0.18
Loading, min	2.00	2.00	2.00	1.35
Unloading, min	1.11	1.33	0.86	0.49
Excavator with bucket, m^3	3.46	4.0	3.22	2.02

Fig. 4 shows the dependence of the transport cycle of dump trucks on the depth of the pit, and it should be noted that we can increase the road gradient for articulated dump trucks up to 35% and for tracked dump trucks up to 45%, which can significantly reduce the time of the transport cycle.

We used the speed recommended by the manufacturers for the articulated dump trucks at road gradients of 20...30% for the loaded dump truck at 3.0 km/h. The world experience of their use confirms that the speed of movement in a pit is 8...15 km/h. In Ukraine, this is confirmed by the experience of VESCO PJSC. As can be seen from Figure 4, the route duration of the articulated dump trucks is the longest and it can be explained by the low speed.

It should be noted that when the distance of rock mass transportation is within 300...500 m, the time of the route components related to manoeuvres, loading and unloading of dump trucks is 20...30% of the transport cycle time.

Constructively, the main purpose of articulated dump trucks is to work in the most unfavourable conditions, where they prove themselves. If we calculate the prime cost of transportation, compared to 4×2 dump trucks, they will be competitive due to a 1.4...2.1 times reduction in transportation distance. This figure will increase even more if we compare it with tracked dump trucks.

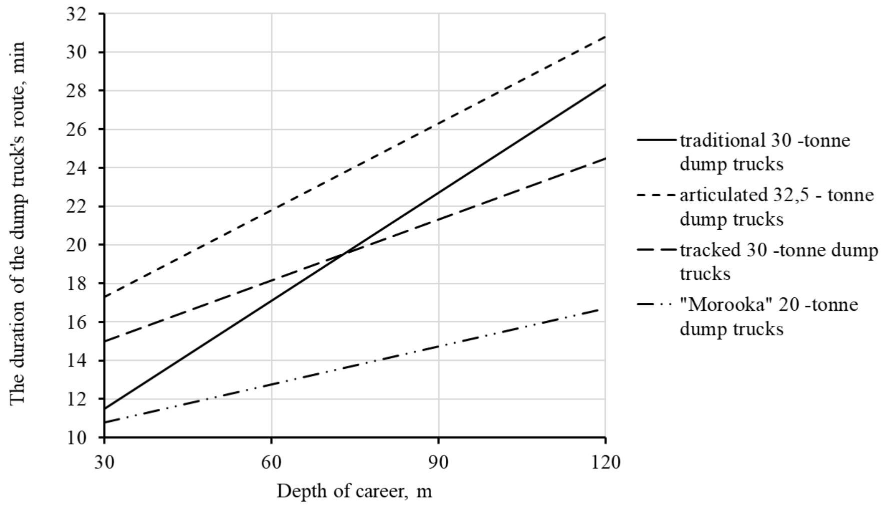


Figure 4 – Dump truck route duration depending on the depth of the open pit

Thus, using articulated and tracked dump trucks in a non-metallic quarry is reasonable. Having established the duration of the transport cycle for dump trucks, it is possible to calculate the productivity of each of them using the formula

$$\Pi_c = q\frac{T_{sh}}{T_p}\cdot k_{sh}\text{, t/shift} \qquad (9)$$

where q – weight of cargo in the dump truck body, t; T_{sh} – shift duration, min; T_p – duration of the dump truck route, min; k_{sh} – shift usage ratio.

Figure 5 shows graphs of dump truck productivity versus pit depth, which show that wheeled dump trucks reduce productivity more intensively than crawler trucks, due to the significant reduction in transport distance for the latter.

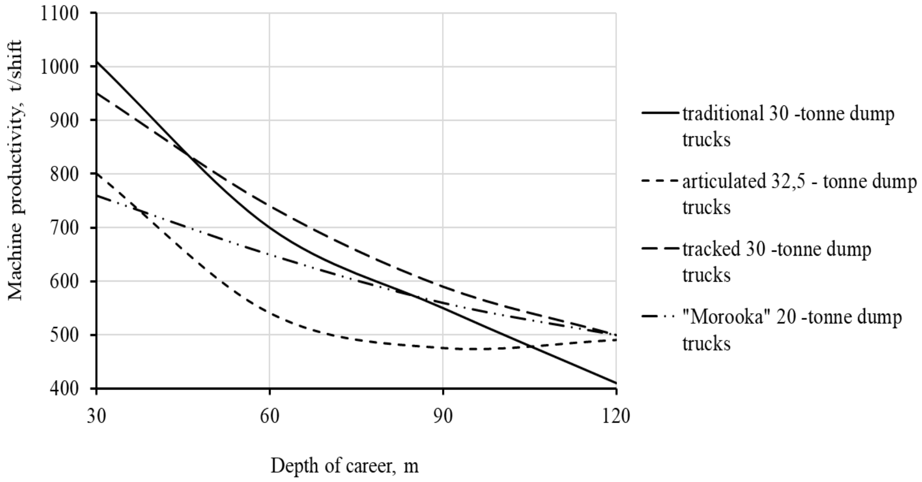


Figure 5 – Graph of dump truck productivity versus pit depth

It should be noted that these dump trucks work in tandem with steep trenches. Figure 6 shows a diagram of the volume of dump truck transport work (t·km).

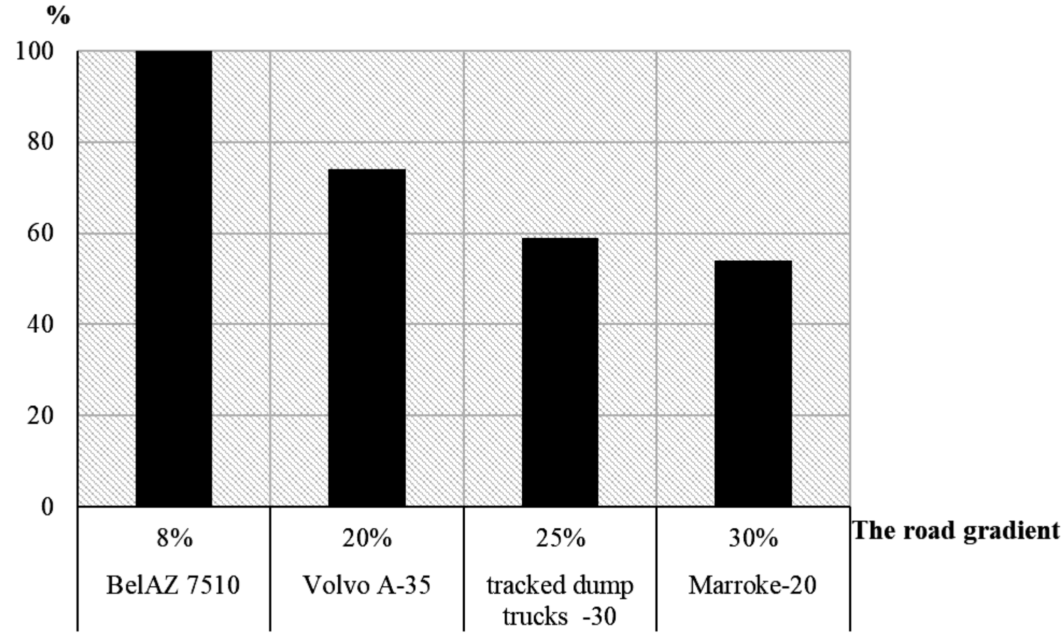


Figure 6 – Dump truck transport workload

As seen from Fig. 6, due to reduced transport distance, crawler dump trucks must perform almost 40% less transport work (t·km) than wheeled dump trucks to transport the extracted raw materials in the quarry. This reduction in transport work leads to decreased fuel, lubricant consumption and exhaust emissions. This significantly minimises environmental pollution.

4. Conclusions

The research has determined the feasibility of introducing tracked and articulated dump trucks. In accordance with the goal, it was found that the most extended transport distances with an increase in the depth of the non-metallic quarry from 30 m to 120 m are observed for wheeled dump trucks with a 4×2 wheel formula. Reduction of transport distances due to the usage of steep road gradients was found for crawler dump trucks.

The dependences of the indicators affecting the length of the route and the duration of the trip for crawler dump trucks during deepening of mining operations were calculated. The longest trip duration within a non-metallic quarry was established for an articulated dump truck at a quarry depth of 60 m, which was 22 minutes, and the shortest for a 20-tonne crawler dump truck, which reached 13 minutes. Using 30-tonne crawler machines allows for a trip in 18–19 minutes.

The performance of dump trucks when transporting rock mass from different depths of the open pit suggests that using wheeled dump trucks with a capacity of 30 tonnes and the same capacity as crawler dump trucks gives an advantage to crawler trucks. This is due to a reduction in manoeuvring time near the face and at the unloading site, as well as a reduction in the lifting route of the rock mass.

Conflict of interest

Authors state no conflict of interest.

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ПРО ДОЦІЛЬНІСТЬ ВПРОВАДЖЕННЯ ШАРНІРНО-ЗЧЛЕНОВАНИХ І ГУСЕНИЧНИХ САМОСКИДІВ НА НЕРУДНИХ КАР'ЄРАХ

Давіденко Н. , Анісімов О.

Анотація. Метою публікації є визначити доцільність застосування на нерудних кар'єрах різних видів самоскидів з урахуванням відстаней транспортування, тривалості рейсу, а також продуктивності при перевезенні гірничої маси від вибоїв до поверхні. Для досягнення поставленої мети були використані наступні методи дослідження: аналіз сучасного кар'єрного транспорту, аналітичний – для встановлення параметрів тривалості рейсу і продуктивності самоскидів, графічний – для пошуку оптимального типу самоскидів, оперативного моніторингу – для встановлення часових параметрів роботи гірничого обладнання. Виконано огляд сучасного застосування самоскидів в умовах розробки нерудних кар'єрів, що дозволило виділити самоскиди з колісною формулою 4×2, шарнірно-зчленовані та гусеничні. Зроблений аналіз роботи транспортних засобів в різних умовах. Це дозволило обґрунтувати параметри роботи транспортних засобів і визначити чинники, що впливають на продуктивність самоскидів. Результатами дослідження є встановленні залежності довжини траси та тривалості рейсу самоскидів від глибини вибою нерудного кар'єру, а також продуктивності відповідних машин. Для гусеничних самоскидів встановлені параметри роботи самоскидів і формула для визначення часу на під'їзд до вибою для навантаження гірничою масою, а також для розвантаження на відповідному майданчику. Отримана залежність під'їзду самоскиду дозволяє встановити продуктивність гусеничної машини, з урахуванням використання повноповоротної платформи (кабіна і кузов знаходяться на єдиній базі що обертається), що виключає операції пов'язані з маневруванням на робочому майданчику і підвищує продуктивність таких машин. Встановлена довжина траси при використанні транспортних машин з урахуванням збільшення ухилу для гусеничних самоскидів. Наукова новизна результатів дослідження полягає у визначені залежності показників довжини траси та тривалості рейсу самоскидів при поглибленні гірничих робіт.

Ключові слова: транспортування гірничої маси**,** кар'єр, колісні самоскиди, гусеничні самоскиди, тривалість рейсу автосамоскиду, продуктивність самоскиду.