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SUBSTANTIATION OF THE WHEEL LOADER EMPLOYMENT AT DIMENSION STONE QUARRIES IN UKRAINE

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EXTENDED ABSTRACT

In Ucraina negli ultimi anni, la tecnica dello sfruttamento delle pietre ornamentali (*dimensional stone*) ha animato molta attenzione grazie della individuazione di nuovi siti estrattivi, a cui consegue la necessità di attuare una pianificazione efficace, per una produzione sistematica ed economicamente vantaggiosa.

Negli ultimi 15 anni, nel settore lapideo ucraino sono state usualmente impiegate le caricatrici gommate (*wheel loaders*). Tuttavia, ancora non tutte le aziende utilizzano a pieno il potenziale di questi mezzi, sia in termini spaziali che temporali. L'obiettivo di questo articolo è di dimostrare la possibilità di utilizzare le caricatrici gommate in maniera indipendente o associata ad altri tecniche di carico e di trasporto, al fine di efficentare l'attività estrattiva nei siti in produzione. Le caricatrici gommate utilizzate nello sfruttamento delle pietre ornamentali ad alta resistenza sono state studiate come una innovazione nell'ambito delle tecniche di estrazione delle rocce in Ucraina e nel mondo. Tuttavia, vi è una scarsità di informazioni riguardo le prestazioni delle caricatrici gommate sia dal punto di vista numerico che economico.

Lo studio attuale descrive il modo più efficace di impiego delle caricatrici gommate nelle cave di pietre ornamentali in Ucraina e mostra l'ampio vantaggio economico del loro uso. A tal fine, sono stati raccolti ed analizzati i dati sulle prestazioni delle tecniche di sfruttamento delle pietre ornamentali, con lo scopo di determinare quali di essi siano le più economiche e quali quelli le più versatili. E' stato inoltre analizzato il carico e il trasporto di blocchi commerciali e dei prodotti di scarto, utilizzando rispettivamente 3 e 4 tecniche alternative, selezionando quelle ritenute più idonee e più vantaggiose. L'insieme dei dati analizzati è stato raccolto in vari siti d'interesse, ovvero presso la cava di gabbro a Nord di Kamianobridske (gabbro nero grezzo "GB2 Kometa Black"), la cava di sienite quarzosa di Chovnivske (granito verde "Chovnovsky") e la cava di gabbro di Volodarsk-Volynske ("bel" gabbro nero "GB6 Nero Notte"), localizzati tutti nell'Ucraina settentrionale, precisamente nel settore centrale della regione di Zhytomyr.

Dall'analisi dei dati raccolti è emerso che l'uso combinato della caricatrice gommata con l'autocarro con cassone ribaltabile, per il carico e per il trasporto di prodotti di scarto, ha un produttività fino a 1.8 volte superiore rispetto alle altre 2 tecniche confrontate.

In particolare è stato esaminato un totale di diversi blocchi con volumi compresi tra 185-195 m^3, quindi sono stati analizzati e considerati i costi operativi, anche in termini di tempo, i costi di produzione, oltre ai rendiconti finanziari.

Si è potuto quindi constatare che le spese per il caricamento e il trasporto dei blocchi commerciali sono state considerevolmente ridotte utilizzando, per tutte le operazioni, le caricatrici gommate. Questa differenza significativa è rappresentata dalla riduzione del costo del carburante, dell'ammortamento e dalla evidente diminuzione del lavoro e del tempo impiegato.

Per quanto riguarda le spese per il carico e il trasporto dei prodotti di scarto, l'uso della caricatrice gommata è risultato essere più costoso rispetto alla combinazione della caricatrice gommata con l'autocarro ribaltabile. Ciò può essere giustificato dal maggior numero di viaggi necessario per uno stesso volume di prodotti di scarto e l'aumento dei tempi dei costi di ammortamento. Questo studio dimostra quindi che i benefici ottenuti dall'uso delle caricatrici gommate, come proposto, rendono questo mezzo idoneo alla coltivazione delle pietre ornamentali rappresentando una scelta auspicabile, quanto economicamente vantaggiosa, per un'ampia gamma di aziende operanti nel settore.

In conclusione ogni azienda, nella pianificazione delle propria attività estrattiva, deve considerare alcune caratteristiche che sono specifiche delle cave di pietre ornamentali: la distanza del trasporto, la produttività che si vuole raggiungere attraverso uno sfruttamento sistematico della cava, il grado di fratturazione della roccia, il peso per unità di volume della roccia, le tecniche di scavo adottate, la conformità tra le diverse tecniche di sfruttamento e altri aspetti naturali, congiuntamente a fattori tecnologici ed economici.

ABSTRACT

The study describes the most effective way of using wheel loaders at typical Ukrainian dimension stone deposits, and shows the economic benefits of their use. The loading and transportation of commercial blocks (LTB) and waste products (LTW) are analyzed, using respectively 4 and 3 alternative techniques. The most eligible techniques are then selected. It has been found that financial expenses for LTB can be reduced using the wheel loader for all operations. As regards the expenses related to LTW, the use of the wheel loader is more costly than the combination of wheel loader and dump truck. This study therefore indicates that the benefits gained from using wheel loaders make them a desirable choice across a wide range of companies.

***Key words**: dimension stone, loading technique, transportation technique, wheel loader, dump truck, time expenditures, economic efficiency*

INTRODUCTION

The technique of dimension stone exploitation has received much attention in recent years due to the current discovery of new dimension stone deposits in Ukraine. Approximately 220 dimension stone deposits have been registered in Ukraine up to now. A significant part of the Ukrainian dimension stone deposits (45%) is located within the Ukrainian shield in Zhytomyr region (Fig. 1) (SSGMRU, 2013). However, not all of them have been successfully exploited.

In Ukraine, wheel loaders started to be exploited about 30 years ago at deposits of loose rocks. However, during the last 15 years the use of this equipment has increased from 10 to 80% at dimension stone quarries due to their manoeuvrability and universality (NPK Gemos Limited, 2006; Spec-Technika Inc., 2014). Although wheel loaders have been traditionally used in the Ukrainian stone sector, many companies still use a different combination of dimension stone exploiting techniques. Furthermore, not every company still uses the full potential of loaders both in terms of space and time. Hence, the goal of this paper is to substantiate the use of wheel loaders independently or together with some types of loading and transportation (LT) techniques.

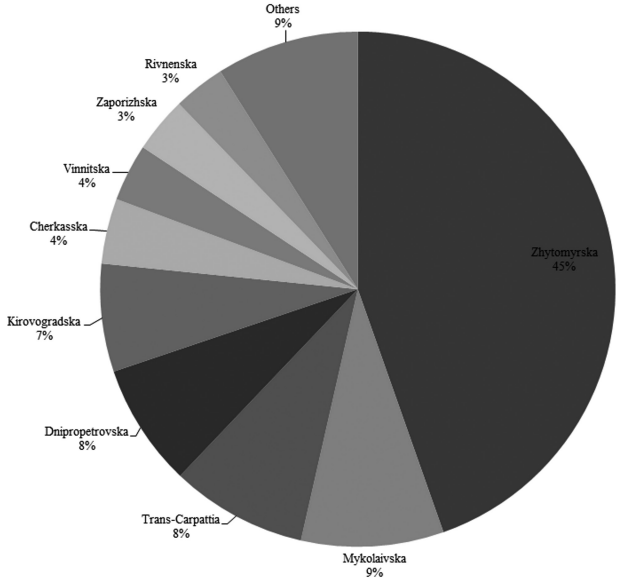

Fig. 1 - Ukrainian reserves of dimension stones by regions

The wheel loaders used for high-strength dimension stones exploitation have been studied as an innovative dimension stone (Melnikov, 1968; Bakka, 1982; Karasiov, 1993; Shpanskii, 1993; Sinelnikov, 2005) and loose rocks (Tomakov & Naumov, 1986) exploitation technique in Ukraine (Bakka, 1982; Karasiov, 1993) and in the World (The Geological Society, 1999; NPK Gemos Limited, 2006). Other works describe the use of wheel loaders as a high-performance technique (Cardu & Lovera, 2002; Bychkov, 2003; Kalinin, 2005; Kokynina, 2006). Nevertheless, there is a lack of explanation on the wheel loaders performance in numerical and monetary terms for the various operations. The current study describes the most effective way of using wheel loaders at typical Ukrainian dimension stones deposits, and shows the economic benefits of their use.

METHODOLOGY

Performance data of dimension stone exploitation techniques was measured, in order to determine which of them are the most economic and the least labour-intensive. The LTB and LTW were analyzed, using respectively 4 and 3 alternative techniques. The most eligible of them were then selected.

The data were collected at the Kamianobridske North gabbro Deposit (coarse dark gabbro "GB2 Kometa Black"), Chovnivske quartz syenite deposit (green granite "Chovnovsky") and Volodarsk-Volynske gabbro deposit (fine black gabbro "GB6 Notte Nero"), which are located in the north of Ukraine in the central part of Zhytomyr region. The main characteristics of the research conditions are described in Table 1.

At these deposits, as well as at the overwhelming majority of dimension quarries of this type (Karasiov & Bakka, 1997), a two stage system of blocks production is used (see Fig. 2).

The first stage consists in exploiting blocks whose volume

Mohs hardness	7
Density	2700-3230 kg/m^3
Bench height(exploitation is carried out by subbanches)	6 m
Transport incline	1-21% (average 9%)
Transportation distance (one way) to: ***- the commercial blocks storage*** ***- the waste storage***	 150-180 m 250-300 m

Tab. 1 - Brief characteristics of the research conditions

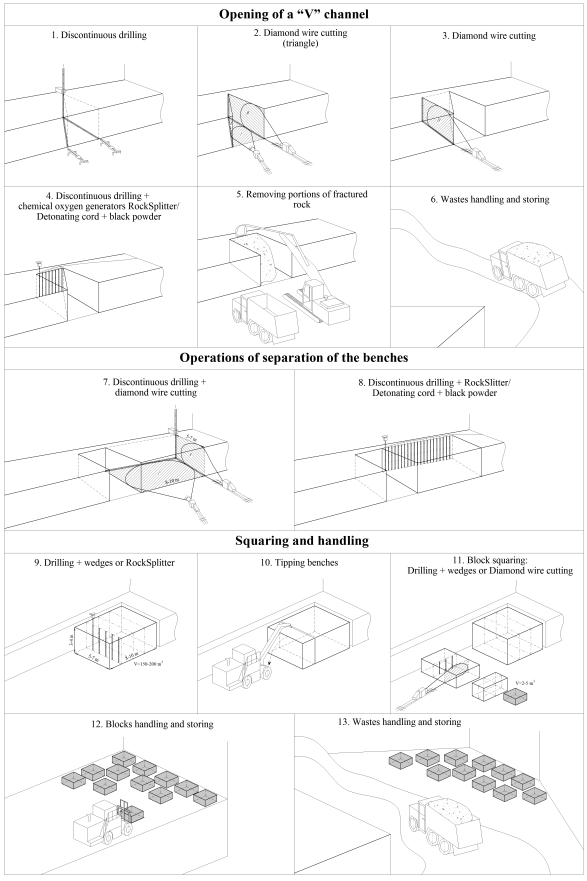

Fig. 2 - Two stage system of blocks production

is approximately 150-200 m^3. The second stage involves the subsequent division into benches, which are then overturned and cut into commercial volumes. The commercial blocks and waste products are then loaded and transported to the blocks storage and to the stockpile accordingly.

A total of several blocks with volume 185-195 m^3 were investigated in field conditions and then operating costs, time expenditures, production costs and financial statements were analyzed and considered. In all experimental cases the average block sizes fluctuated within the limits 3-4 m^3. Total volume of loaded and transported blocks was 56-58 m^3. The total volume of loaded and transported waste products was 133-136 m^3.

The equipment employed for the LTB and LTW is specified in Table 2.

The time required for the operations was calculated using the formula below:

$$T = (t_{set} + t_{sl} + t_l + t_{td} + t_{cu} + t_{tr} + t_m + t_{fc}) \, n_r \qquad (1)$$

where:

t_{set} - equipment setting into the working position;
t_{sl} - slinging (applicable for the hoisting crane);
t_l - block/waste products loading on the truck (applicable for the hoisting crane, excavator and wheel loader use);
t_{td} - block/waste products transportation;
t_{cu} - the cargo unloading;
t_{tr} - movement of empty truck for new blocks loading;
t_m - manoeuvring;
t_{fc} - face cleanup (applicable for the bulldozer and wheel loader);
n_r - number of trips.

Type of operations	***Equipment options***		
	Kamianobridske North gabbro deposit	***Chovnivske quartz syenite deposit***	***Volodarsk-Volynske gabbro deposit***
Trade blocks loading on hauling units	crane KC-5363	crane KC-55732-24	-
	excavator Volvo EC460D	excavator VEKS EO 4124	excavator Hitachi EX 800H
	wheel loader CAT 988H (load rating 11.4 t)	wheel loader Volvo-220	wheel loader Komatsu WA600
Blocks transportation to the warehouse	dump truck KrAZ 65055 (capacity 16-18 t)	dump truck KrAZ 7511C4	dump truck KrAZ 65055
	wheel loader CAT 988H	wheel loader Volvo-220	wheel loader Komatsu WA600
Work platform cleanup	bulldozer DZ-9 (D-275A, D-180)	bulldozer DZ-9 (D-275A, D-180)	bulldozer DZ-9 (D-275A)
	wheel loader CAT 988H	wheel loader Volvo-220	wheel loader Komatsu WA600
Loading of waste products on hauling units	excavator Volvo EC460D	excavator VEKS EO 4124	excavator Hitachi EX 800H
	wheel loader CAT 988H	wheel loader Volvo-220	wheel loader Komatsu WA600
Oversize blocks transportation	dump truck KrAZ 65055	dump truck KrAZ 7511C4	dump truck KrAZ 65055
	wheel loader CAT 988H	wheel loader Volvo-220	wheel loader Komatsu WA600
Optional accessories displacement	crane KC-5363	crane KC-55732-24	-
	wheel loader CAT 988H	wheel loader Volvo-220	wheel loader Komatsu WA600

Tab. 2 - The equipment employed in investigated operations

RESULTS

Data obtained in previous studies (Filipova & Kotenko, 2011; Karimbetova & Kotenko, 2013) show that the use of wheel loaders resulted in a general productivity increase and in considerably lower material expenses than those incurred using a combined exploiting technique. The difference between economic efficiency and labor-intensiveness of 7 alternative techniques was identified. Figure 3 shows the results obtained from the research.

As it can be seen, the use of the wheel loader [1] can reduce the time for LTB by 2 times, in comparison with the combination [3] and by 4 times, in comparison with [2] and [1]. It is consistent with results obtained in previous studies (Filipova & Kotenko, 2011; Karimbetova & Kotenko, 2013; Karimbetova, 2013). It can be observed that the loading speed, rate of movement, power of an engine and controllability of the wheel loader is higher than the dump truck capacity (Caterpillar Inc., 2008; AUTOKRAZ PJSC, 2015).

Figure 4 displays the results obtained after time expenditure examination during the waste products loading and transportation.

As can be seen, the use of the combination [2] is 1.5 hours faster than the use of [3]. Significantly, the time saving is even higher (5.5 hours less) compared to the use of [1]. Furthermore, the combination [2] can transport 1.5 times more waste products than the options [1] and [3] (Caterpillar Inc., 2008; AUTOKRAZ PJSC, 2015).

Additionally, each technique was evaluated in terms of its economic efficiency, taking into account labor and consumable costs. The operating costs for LTB and LTW can be calculated using the formula below:

$$CO = n_w T a_s + \Sigma(C_f T_u) + \Sigma(nu\ Tu\ A),\ MU \qquad (2)$$

where:

n_w number of workers;
T total operating time (formula 1);
a_s amount of salary for 1 worker per hour;
C_f fuel costs per hour for each unit;
T_u total operating time of each unit;
n_u number of equipment units;
A payment amount per period (amortization costs).

Only the depreciation costs of equipment for the LTB were calculated (data of accounting reporting standards have not been taken into account). Figure 5 demonstrates the results obtained from the research during the LTB. As it can be seen in the figure, the use of the wheel loader for LTB is as much as 2 times more profitable than the [1], [2] and [3] techniques (Tab. 3).

The results obtained from the research during the LTW are shown in Fig. 6. The use of the combination [2] for LTW is more than 1.8 times higher compared to the techniques [1] and [3] (Tab. 4).

It is important to consider that transport costs depend directly on the transport distance. As it can be seen, the use of wheel loaders is more beneficial with the blocks storage location within 200 m from the working place (Fig. 7).

In terms of the Kamianobridske deposit, it should be noted that the commercial blocks storage is located on the quarry daylight

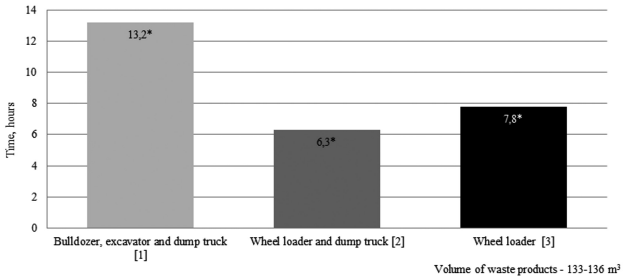

Fig. 4 - Averaged time expenditures for waste products loading and transportation
** time for lunch breaks, shift changes, repairs, downtimes is not taken into account*

Costs	*[1]*	*[2]*	*[3]*	*[4]*
Fuel	100%	71.4%	54.7%	39.8%
Amortization	71.4%	85.7%	100%	38.1%
Labor	100%	51.6%	41.1%	5.3%

Tab. 3 - Costs for LTB (56-58 m³ of commercial blocks), share
** time expenditures, quantity of workers and equipment units are taken into account*

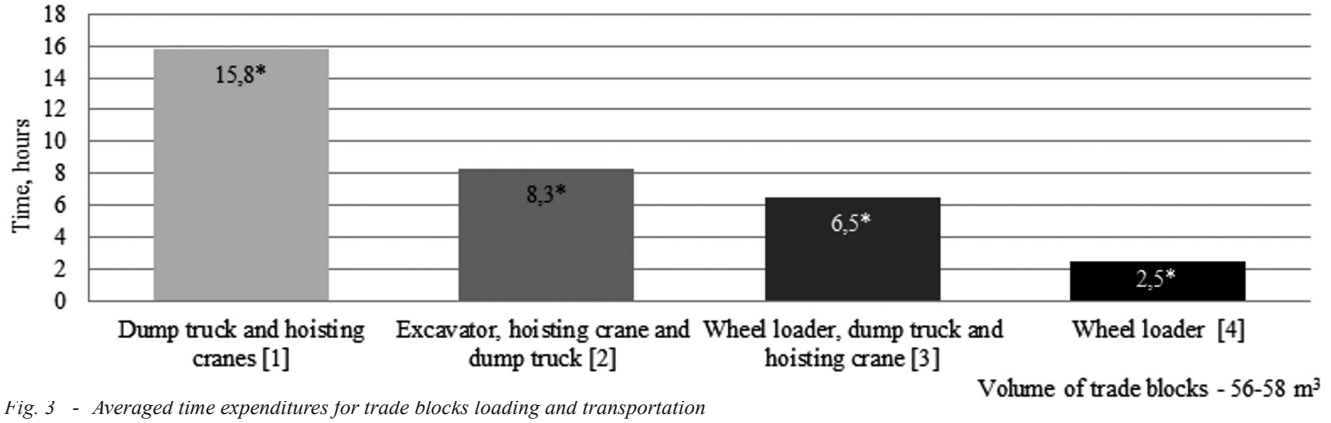

Fig. 3 - Averaged time expenditures for trade blocks loading and transportation
** time for lunch breaks, shift changes, repairs, downtimes is not taken into account)*

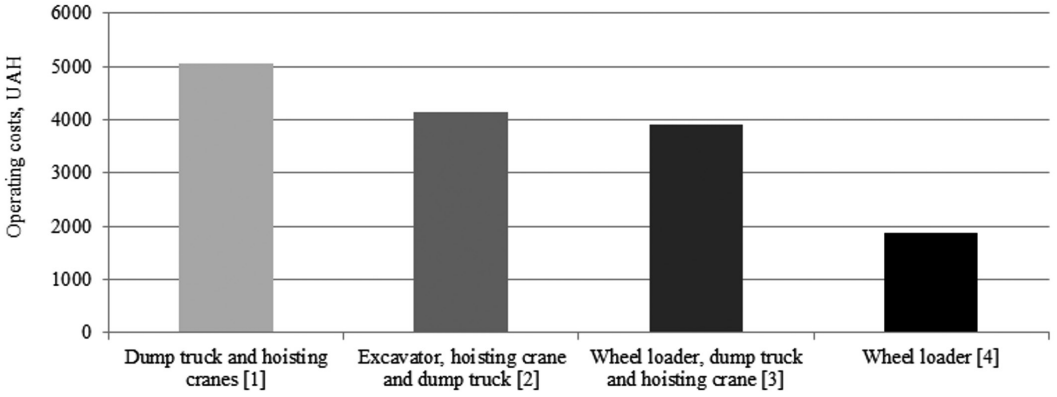

Fig. 5 - Financial expenses for trade blocks loading and transportation

surface. It is acceptable to set up the storage at the abandoned area of the first bench, in order to reduce the costs of the company. Investigation on commercial blocks storage location is currently in progress to determine if the predicted efficiencies can be achieved. Moreover, the operating environment of Kamianobridske deposit provides transport inclines of up to 21% that oversize the optimal index 8-10% by 2 times (Tomakov & Naumov, 1986). Consequently, it is slightly problematic to determine the optimal costs of carrying out transportation operations, as the quarry requires the road optimization. Nevertheless, the data obtained may provide a more widespread adoption of the suggested techniques and will focus company owners` attention on LT technique reorganization.

CONCLUSIONS

Prior works (Karasiov & Bakka, 1997; Bakka, 1982; Bychkov, 2003; Kokynina, 2006) have documented the effectiveness of wheel loader use. However, these studies have either been short-term studies or have not focused on the economic substantiation of using wheel loaders at dimension stone quarries.

In this study the effectiveness of LT operations with several blocks were tested at several high-strength dimension stone deposits. It was found that costs due to LTB were reduced using the wheel loader for all operations. This significant difference is accounted for in the reduction of fuel, amortization, time and labor costs. As regards due to expenses for LTW, the use of the wheel loader was more costly than the combination of wheel loader and dump truck.

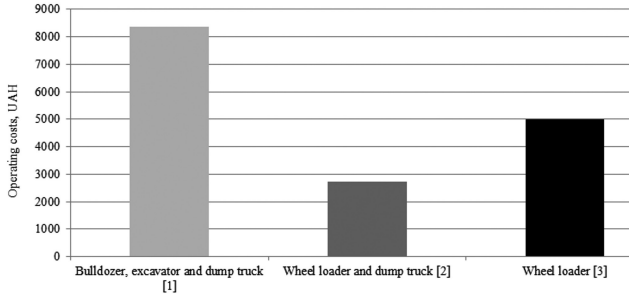

Fig. 6 - Financial expenses for waste products loading and transportation

Costs	*[1]*	*[2]*	*[3]*
Fuel	95.2%	39.4%	100%
Amortization	100%	26.7%	35.6%
Labor	100%	31.8%	19.7%

Tab. 4 - Costs for LTW (133-136 m³ of waste products), share
** the total amount of truck rides for the same volume of waste products, time and amortization expenditures are taken into account*

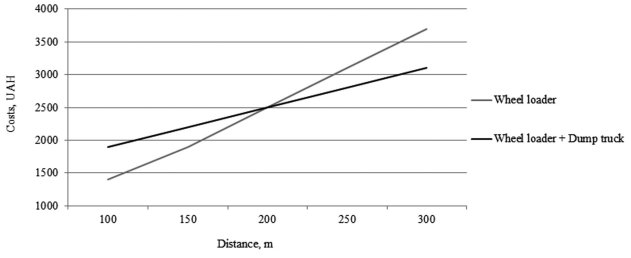

Fig. 7 - Transportation costs

Job	*Wheel loader*	*Dump truck*
Removing and dumping earth and debris	*effective*	*effective*
Making and maintaining quarry yard and ramps	*effective*	*effective*
Making debris bed for bench tipping	*effective*	*fairly adequate*
Tipping benches	*effective (with changeable units or ropes)*	*effective (with ropes)*
Block handling	*effective*	*fairly adequate*
Equipment handling	*effective*	*fairly adequate*
Wastes handling	*fairly adequate*	*effective*

Tab. 5 - Possibilities of use of handling machines in quarrying operations

This can be justified by the increase of the total quantity of travels for the same volume of waste products, time and amortization costs.

Consequently, using a wheel loader significantly reduces the necessity for large numbers of workers at the same working place. Also, it becomes possible to reduce expenses on a large number of mechanization units. A quite significant advantage of wheel loaders is their maneuverability and ability to serve several working areas sequentially in a short time.

This study therefore shows that the benefits gained from using wheel loaders as proposed make them a desirable choice across a wide range of companies. However, every company has to consider some specific characteristics of each dimension stone deposit: the transportation distance, desired productivity of the quarry, rock mass fracturing, rock density, excavation techniques, compliance between different exploitation units and other natural, technological and economic-organizing factors.

Future work should therefore include the study of the aforementioned compliance between the production capabilities of excavation, loading and transportation techniques. It is also planned to conduct similar research at analogous deposits in Ukraine to develop a methodology to improve the technique of Ukrainian dimension stone exploitation.

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