Analysis of Quarrying Equipment Operating Cost Structure

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Abstrakt

The mining equipment in quarrying comes in similar configurations regardless of the type of the useful deposit processed. The sensible choice of quarrying mining equipment components, such as transport means, loaders, excavators and processing machines should be based on a detailed analysis of the technical and economic aspects involved, while taking into account the deposit conditions.To determine the cost structure of the mining equipment for the analysed deposit conditions, five configurations of quarrying equipment were suggested, differing by preliminary crushing location, the number of machines, the number of employees (operators) and the length of transport routes The analysis presented in this paper demonstrates the cost structures of using various quarrying equipment configurations for deposits characterised by substandard quality characteristics. Further work should be conducted to determine the component usage costs of modified equipment in quarrying deposits of reduced quality.

Keywords: mining equipment, operating cost, raw materials, mining cost structure

Introduce

The main mining equipment in quarrying involve haul trucks, wheel loaders, excavators and processing machines. This equipment comes in similar configurations regardless of the type of the useful deposit processed. The sensible choice of quarrying mining equipment components, such as transport means, loaders, excavators and processing machines should be based on a detailed analysis of the technical and economic aspects involved, while taking into account the deposit conditions. It also seems necessary to analyse the operating cost structure in relation to the configuration of various systems according to mining and geological conditions. Nowadays, this issue can be considered even more important, as in recent years it has become necessary to quarry deposits which are seen as being of a lower quality. General costs structure of mining equipment costs in quarrying is presented on the Figure 1.

Assumptions adopted for analysis

This study contains a decomposition and analysis of costs structure which constitute the main cost components of operating the mining equipment making up various potential equipment configurations. These include:

- fuel or energy costs,
- leasing costs,
- total maintenance and repair (TMNR),
- tyre costs (haul trucks),
- employee costs – payroll (Patyk, Bodziony, 2018; Patyk, 2016; Patyk, 2019).

Furthermore, the analysis was performed for a limestone deposit characterised by numerous karst inclusions, which led to classifying 10% of the excavated material as spoils. It is also necessary to organise additional transport of this component of excavated material to the waste dump, which increases quarrying costs. This analysis assumed 500 Mg/h extraction performance for each quarrying equipment configuration. It was also assumed that the machines were leased out by their manufacturers and maintained by their external service centres. The cost of purchasing machines was not taken into account, as most machines used in mining are leased.

All machines, with the exception of haul trucks, were used on two shifts with the effective time T_e = 7 hours. It was assumed that the analysed machines would operate 25 days, i.e. 350 hours per mth.

Configuration of the analysed quarrying equipment

To determine the cost structure of the mining equipment for the analysed deposit conditions, five configurations of quarrying equipment were suggested, differing by preliminary crushing location (Fig. 2), the number of machines, the number of employees (operators) and the length of transport routes (Patyk, 2019).

Alternative W1 is the only alternative in which preliminary crushing takes place near the face, with the shortest transport routes and the lowest number of mining system components.

Alternative W2 is the only alternative in which intermediate product is transported from the mobile crusher to the processing plant via a belt conveyor, with a medium length of haulage roads.

Alternative W3 involves preliminary crushing of material in a stationary crusher, with the longest transport routes, and the optimum proportion of intermediate product in the seam. In this system, the extracted rock is crushed by two crusher systems to yield 2% more intermediate product than the other alternatives. A more compound crushing system ensures increased exploitation of the seam and reduces overburden(Patyk, 2019).

The figure 2 presents the surroundings of the operational area of the analysed mining equipment.

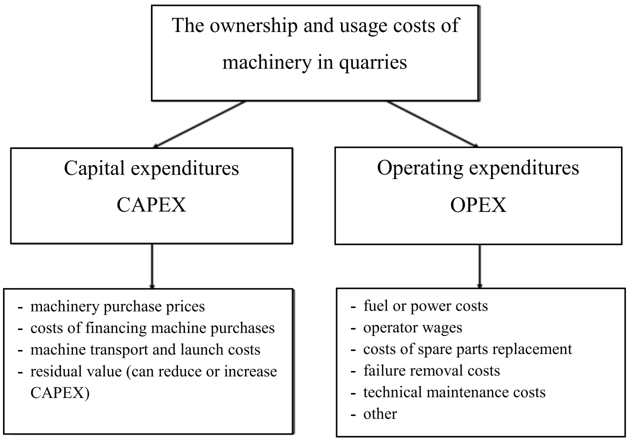

Fig. 1. Components of the total costs of ownership and operation of a single-bucket excavator
Rys. 1. Składniki całkowitych kosztów posiadania i użytkowania koparki jednonaczyniowej

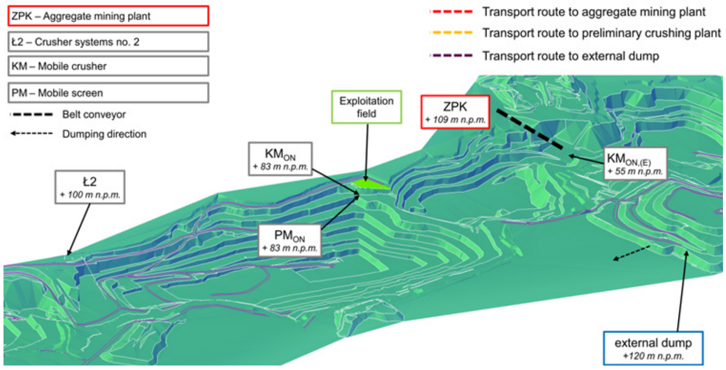

Fig. 2. Preliminary crushing location in various decision variants
Rys. 2. Lokalizacja wstępnego kruszenia w różnych wariantach decyzyjnych

The costs were divided into: fixed – depending on the number of machines in a given system, and variable – depending on the lengths and configurations of transport routes and other technological processes, such as loading and processing of the raw material. Fixed costs included machine leasing costs, TMNR, payroll costs and tyre replacement costs.

Another factor taken into account was the usage rate of the transport system, which provided information about the dump bed fill level. Once the fill level fell below 50%, some haul trucks were dispatched to serve other transport processes taking place in the quarry at the time. This was the case for D1 routes – the transport of off-spec material to the spoil heap.

An analysis of the cost components of quarrying mining equipment

Energy carrier consumption

The average fuel consumption of haul trucks largely depends on the hauling route configuration (rolling resistance), on the number of ascents and descents (Fig. 3) and the average speed of the operating haul truck. Three process routes were distinguished on the basis of the transport process being used (Table 3):

- D1 – the off-spec material transport route from preliminary crushing to the spoil heap, - transporting the mix to the spoil heap
- D2 – the intermediate product transport route from preliminary crushing to the aggregate processing plant – the transport of the intermediate product to the aggregate processing plant for use in a further processing stage,
- D3 – the output transport route from under the quarry face to preliminary crushing – the transport of the output for classification (screening or crushing) as a mix or intermediate product.

Table 3 presents the length of the individual transport routes, the average fuel consumption of the transport equipment and the usage rate of the dump bed W_{WUT} for a single work shift.

For other machines, the actual consumption of fuel or other energy carriers corresponding to the respective processes were assumed (Table 4).

The costs of fuel consumption were calculated on the basis of the operating time of machines over one mth (350 hours), the average price of one litre diesel oil –3.26 PLN net and electric power – 0.40 PLN net of 1kWh, the average fuel and power consumption for machines and the average planned fuel consumption in a given transport route for haul trucks, as well as the number of active shifts (1).

$$\begin{cases} K_{P.W_{Wi}} = K_{P_{Wi.D1}} + K_{P_{Wi.D2}} + K_{P_{Wi.D3}} \\ K_{P.M_{Wi}} = D \cdot T_e \cdot Z \cdot [\Sigma Q_{P.ON_k} \cdot C_{ON} \cdot \Sigma Q_{P.E_k} \cdot C_E] \\ K_{P_{Wi}} = K_{P.W_{Wi}} + K_{P.M_{Wi}} \end{cases} \tag{1}$$

Tab. 3. The average fuel consumption in the analysed process routes for the transport equipment
Tab. 3. Średnie zużycie paliwa na analizowanych drogach technologicznych dla układu transportowego

Route \ Variant	Unit	W1	W2	W3	W4	W5
D1: Length of route to spoil heap[1]	l/h	(38.1)[2]	(41.6)	(36.2)	(38.1)	(38.1)
	m	**1,760**	**2,780**	**3,650**	**1,760**	**1,760**
	%	*18.4%*	*25.0%*	*23.1%*	*18.4%*	*18.4%*
D2: Length of hauling route to the processing plant	l/h	(78.7)	-	(66.9)	(66.9)	-
	m	**1,000**	**-**	**2,860**	**2860**	**-**
	%	*60.4%*	-	*87.9%*	*87.9%*	-
D3: Length of hauling route to preliminary crusher	l/h	-	(80.9)	(69.8)	(69.8)	(80.9)
	m	**-**	**1,220**	**1,720**	**1720**	**1,220**
	%	-	*61.7%*	*80.0%*	*80.0%*	*61.7%*

[1] the transport takes place during the 2nd work shift
[2] average fuel consumption in a given process route expressed in l/h

Tab. 4. The fuel consumption or electrical energy by quarrying mining equipment
Tab. 4. Zużycie paliwa lub energii elektrycznej maszyn górniczych

Machine Type / Name	Installed capacity [kW]	Symbol	Average consumption of energy carriers
Excavator **CAT 345**	317	$Q_{.K}$	39 l/ h
Loader **WA600 HL**	393	$Q_{.Ł}$	40 l/ h
Mobile crusher plant **PowerscreenPremiertrak 1100x800**	205	$Q_{.K\ M}$	28 l/ h
Mobile crusher plant **PowerscreenPremiertrak 1100x800**	185	$Q_{.K\ M}$	148 kW/h
Grading screen **Powerscreen Warrior 2400**	151	$Q_{.P\ M}$	22 l/ h
Belt conveyor	180	$Q_{.P\ T}$	144 kW/h
preliminary crushing + sorting **Crushing plant No. 2 + stationary plant**	1300	$Q_{.K\ S}$	1043 kW/h

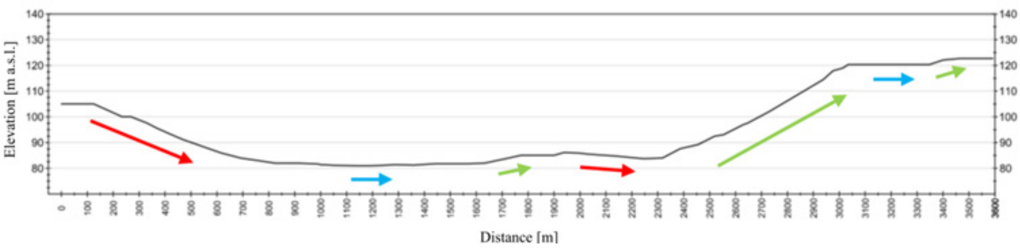

Fig. 3. An example longitudinal profile of the hauling route with marked ascents and descents
Rys. 3. Przykładowy profil podłużny drogi z zaznaczonymi wzniosami i spadkami

where:
K_{PWi} – total energy carrier consumption costs for the quarry equipment in the i-th variant, PLN/mth,
$K_{P.MWi}$ – costs of energy carrier consumption for loaders, crusher-screens and belt conveyors in the i-th variant, PLN/mth,
$K_{P.WWi}$ – fuel consumption costs for the transport equipment in the i-th variant, PLN/mth,

$$\begin{cases} W_{WUT} \geq 50\% \rightarrow K_{P_{Wi.Dj}} = Q_{ON.Dj} \cdot D \cdot T_e \cdot Z \cdot C_{ON} \\ W_{WUT} < 50\% \rightarrow K_{P_{Wi.Dj}} = Q_{ON.Dj} \cdot D \cdot T_e \cdot Z \cdot C_{ON} \cdot 50\% \end{cases} \tag{2}$$

$$\begin{cases} K_{P_{Wi.D1}} = Q_{ON.D1} \cdot D \cdot T_e \cdot Z \cdot C_{ON} \cdot 50\% \\ K_{P_{W1.D2}} = Q_{ON.D2} \cdot D \cdot T_e \cdot Z \cdot C_{ON} \\ K_{P_{W1}} = K_{P_{W1.D1}} + K_{P_{W1.D2}} \end{cases}$$

where:
$K_{PWi.DI}$ – fuel consumption costs for the haul truck in the i-th variant on the j-th route, PLN/mth,
W_{WUT} – transport equipment usage rate, %,
$Q_{ON.Dj}$ – average fuel consumption of the transport equipment operating along the j-th route, l/h.,
D – number of workdays, D=25 days,
T_e – shift effective time, T_e=7 hours,
Z – number of shifts, pcs,
C_{ON} – average net price of diesel oil, C_ON=3,26 PLN/l.
C_E – average net price of power, C_E=0,40 PLN/kWh.
$Q_{P.ONk}$– average fuel consumption of the k-th machine, l/h (Table 4),
$Q_{P.Ek}$– average power consumption of the k-th machine, kWh (Table 4).

Tab. 5. The costs of energy carrier consumption for machines in respective equipment configurations
Tab. 5. Koszty zużycia nośników energii maszyn w poszczególnych układach technologicznych

Energy carrier consumption costs [PLN/mth]	**W1**	**W2**	**W3**	**W4**	**W5**
Haul trucks	100,665	104,174	166,301	166,843	103,175
Other mining equipment	122,087	176,659	237,300	306,901	200,620
Total	**222,752**	**280,833**	**403,601**	**473,744**	**303,795**

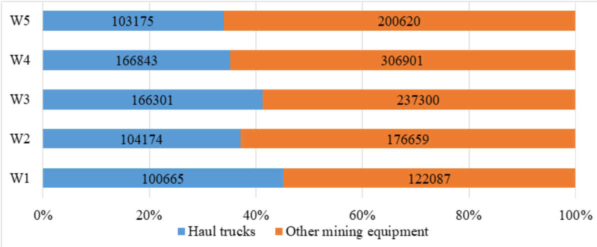

Fig. 4. A comparison of the energy carrier consumption costs for haul trucks and other mining equipment making up the process equipment
Rys. 4. Porównanie kosztów zużycia nośników energii wozideł technologicznych oraz pozostałych maszyn górniczych składających się na układ technologiczny

For the W1 variant, the costs of haul trucks/transport equipment are:

$$\begin{cases} K_{P_{W1.D1}} = 10868 PLN/mth \\ K_{P_{W1.D2}} = 89797 PLN/mth \\ K_{P_{W1}} = K_{P_{W1.D1}} + K_{P_{W1.D2}} = 100665 PLN/mth \end{cases}$$

For other machines and all quarry equipment:

$$\begin{cases} K_{P_{Wi}} = K_{P_{W1}} + K_{P_{W1}} = 100094 + 122087 = 222752 PLN/mth \\ K_{P_{W1}} = K_{P_{W1.D1}} + K_{P_{W1.D2}} = 100094 PLN/mth \\ K_{P_{Wi}} = K_{P_{W1}} + K_{P_{W1}} = 100094 + 122087 = 222752 PLN/mth \end{cases}$$

Table 5 presents the costs of energy carriers for haul trucks and other mining equipment in other variants. Fig. 4 contains a comparison of these costs with the haul truck stock and other mining equipment.

The costs of energy carrier consumption for haul trucks range from 34% in the W4 variant to 45% in the W1 variant. Interestingly, in the variant featuring the longest process routes (W3), these costs represent 41%, while in the variant with the shortest hauling routes (W1) – 45%. The W3 and W4 variants include a stationary crusher-screen device, which generates considerable costs due to power consumption. Furthermore, the total cost of energy carrier consumption in the W1 variant represents about 55% of the costs in the W3 variant. The process equipment presented in the W1 variant generates the lowest energy carrier consumption costs of all the analysed process equipment configurations.

Machine stock size

The amount of mining equipment depends on the configuration of process variants and, in the case of haul trucks, on the length of process routes and the efficiency of the transport equipment, as shown in Table 6 (Patyk, 2019).

Number of employees in respective equipment configurations depends on the number of machines and process equipment configuration. The only difference is present in the case of the preliminary crushing system. Specifically, the stationary crushing machine is operated by two employees, while mobile crusher-screen devices are operated by the loader operators (Patyk, 2019). Table 7 presents the number of employees by variant.

Payroll costs depend on the number of employees and their wages (3). In addition, the wages of haul truck drivers depend on the usage rate of the haul trucks – W_{WUT}. Average wages were adopted, i.e. PLN 4,500/mth net.

$$\begin{cases} K_{W_{Wi}} = K_{W_{Wi.D1}} + K_{W_{Wi.D2}} + K_{W_{Wi.D3}} \\ K_{W.M_{Wi}} = n_{op_{Wi}} \cdot C_W \\ K_{W_{Wi}} = K_{W.W_{Wi}} + K_{W.M_{Wi}} \end{cases} \quad (3)$$

where:
K_{WWi} – total cost of employees in the i-th variant, PLN/mth,
$K_{W.MWi}$ – costs of operators of loaders, crusher-screens and belt conveyors in the i-th variant, PLN/mth,
$K_{W.WWi}$ – costs of haul truck drivers in the i-th variant, PLN/mth,
n_{opWi} – number of machine operators in the i-th variant, pcs,
$n_{WWi.Dj}$ – number of haul trucks in the i-th variant, pcs,
Z – number of shifts, pcs,
C_W – machine operator wages, C_W=4500 PLN/mth netto,
$K_{WWi.Dj}$ – haul truck driver costs in the i-th variant on the j-th route:

$$K_{W_{Wi.Dj}} = \begin{cases} W_{WUT} \geq 50\% \to K_{W_{Wi.Dj}} = n_{W_{Wi.Dj}} \cdot Z \cdot C_W \\ W_{WUT} < 50\% \to K_{W_{Wi.Dj}} = n_{W_{Wi.Dj}} \cdot Z \cdot C_W \cdot 50\% \end{cases} \quad (4)$$

For variant W1, these costs are as follows:

$$\begin{cases} K_{W_{Wi}} = (n_{W_{W1.D1}} \cdot Z \cdot 50\% + n_{W_{W1.D2}} \cdot Z) \cdot C_W = 20250 PLN/mth \\ K_{W.M_{Wi}} = n_{op_{Wi}} \cdot C_W = 18000 PLN/mth \\ K_{W_{Wi}} = K_{W.W_{Wi}} + K_{W.M_{Wi}} = 38250 PLN/mth \end{cases}$$

Table 8 shows employee costs for haul trucks and other mining equipment in other variants. Fig. 5 contains a comparison of fuel costs for haul trucks and other mining equipment.

The structure of payroll costs for machine operators and haul truck drivers is more diversified than for previously calcu-

Tab. 6. Number of machines by variant
Tab. 6. Liczba maszyn w zależności od wariantu

Variant / Machine type	Unit	W1	W2	W3	W4	W5
Haul trucks	pcs.	3	3	5	5	3
Excavator	pcs.	1	1	-	1	2
Loader	pcs.	1	2	2	2	1
Mobile crusher (diesel)	pcs.	1	-	-	-	-
Mobile crusher (electrical)	pcs.	-	1	-	-	1
Stationary crusher	pcs.	-	-	1	1	-
Grading screen	pcs.	-	-	-	1	1
Belt conveyor	pcs.	-	1	-	-	1
Total	**pcs.**	**6**	**8**	**8**	**10**	**9**

Tab. 7. Number of employees in respective equipment configurations
Tab. 7. Liczba pracowników w zależności od wariantu układu technologicznego

Variants	**W1**	**W2**	**W3**	**W4**	**W5**
Machine operators, number of people	4	8	8	10	8
Haul truck drivers, number of people	5	5	9	9	5
Total	**9**	**13**	**17**	**19**	**13**

Tab. 8. The costs of machine operator wages in respective equipment configurations
Tab. 8. Koszty wynagrodzenia pracowników maszyn w poszczególnych układach technologicznych

Employee costs [PLN/mth]	**W1**	**W2**	**W3**	**W4**	**W5**
Haul trucks	20,250	20,250	38,250	38,250	20,250
Other mining equipment	18,000	36,000	36,000	45,000	36,000
Total	**38,250**	**56,250**	**74,250**	**83,250**	**56,250**

lated energy carrier consumption costs. The proportion of haul truck driver wages ranges from 36% in the W2 and W5 variants to 53% in the W1 variant. The variants with the highest payroll costs are the W3 and W4 variants, especially W4. The W2 and W5 variants are characterised by the same level of payroll costs, while for the W1 variant these costs are the lowest, being about 46% of the costs of the W4 variant.

Machine leasing costs

Leasing costs for individual variants depend on the quarrying equipment configuration.

$$\begin{cases} K_{L_{Wi}} = K_{L_{Wi.D1}} + K_{L_{Wi.D2}} + K_{L_{Wi.D3}} \\ K_{L.M_{Wi}} = \Sigma C_{L_k} \\ K_{L_{Wi}} = K_{L.W_{Wi}} + K_{L.M_{Wi}} \end{cases} \tag{5}$$

where:
K_{LWi} – total leasing costs in the i-th variant, PLN/mth,
$K_{L.MWi}$ – costs of leasing of loaders, crusher-screens and belt conveyors in the i-th variant, PLN/mth,
$K_{L.WWi}$ – haul trucks leasing costs in the i-th variant, PLN/mth,
$n_{WWi.Dj}$ – number of haul trucks in the i-th variant, pcs,
C_{Lk} – leasing amount for the k-th machine operating in a given configuration, PLN/mining equipment, (Tab. 9),
C_{LW} – leasing costs for haul trucks, PLN/hour.,
T_e – effective time of haul truck operation during a shift, h,
Z – number of shifts, pcs,
$K_{LWi.Dj}$ – haul truck leasing costs in the i-th variant on the j-th process route:

$$K_{L_{Wi.Dj}} = \begin{cases} W_{WUT} \geq 50\% \rightarrow K_{L_{Wi.Dj}} = n_{W_{Wi.Dj}} \cdot Z \cdot T_e \cdot D \cdot C_{L_W} \\ W_{WUT} < 50\% \rightarrow K_{L_{Wi.Dj}} = n_{W_{Wi.Dj}} \cdot Z \cdot T_e \cdot D \cdot C_{L_W} \cdot 50\% \end{cases} \tag{6}$$

For variant W1, these costs are as follows:

$$\begin{cases} K_{W_{W1}} = (n_{W_{W1.D1}} \cdot Z \cdot 50\% + n_{W_{W1.D2}} \cdot Z) \cdot C_{L_W} \cdot T_e = 94500 PLN / mth \\ K_{W.M_{W1}} = \Sigma C_{L_k} = 125800 PLN / mth \\ K_{W_{W1}} = K_{W.W_{W1}} + K_{W.M_{W1}} = 220300 PLN / mth \end{cases}$$

Table 10 shows leasing costs for haul trucks and other mining equipment in other variants. Fig. 6 contains a comparison of fuel costs for haul trucks and other mining equipment.

The leasing costs for respective quarrying equipment configurations are the least diversified of all the analysed costs. Specifically, the difference between the variant with the lowest leasing costs (W1) and the variant with the highest leasing costs (W4) is about PLN 100 thousand, which is nearly 2/3 of its costs. The proportion of the leasing costs of transport equipment in relation to those of other machines is the most diversified in comparison to other costs and ranges from 34% in the W2 and W5 variants to 64% in the W3 variant.

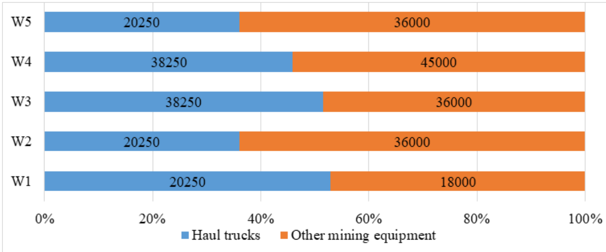

Fig. 5. A comparison of the payroll costs for haul truck drivers and for other mining equipment making up the process equipment
Rys. 5. Porównanie kosztów wynagrodzenia pracowników wozideł technologicznych oraz pozostałych maszyn górniczych składających się na układ technologiczny

Tab. 9. Quarrying machine leasing costs C_{Lk}
Tab. 9. Stawki leasingu maszyn górniczych C_{Lk}

Machine	Excavator	Loader	Mobile crusher (diesel)	Mobile crusher (electrical)	Stationary crusher	Grading screen	Belt conveyor
Rate, PLN/mth	27,300	50,000	48,500	48,500	-	20,000	10,000

TMNR costs (total maintenance and repair costs)

The total maintenance and repair costs of haul trucks depend on the number of machines and the usage rate of the dump bed, W_{WUT}, and for other machines on their number and unit cost C_{TMNR}:

These costs were calculated in a similar manner as the costs mentioned above.

$$\begin{cases} K_{T_{Wi}} = K_{T_{Wi.D1}} + K_{T_{W1.D2}} + K_{T_{W1.D3}} \\ K_{T.M_{Wi}} = \Sigma C_{TMNR_k} \\ K_{T_{Wi}} = K_{T.W_{Wi}} + K_{T.M_{Wi}} \end{cases} \tag{7}$$

where:
K_{TWi} – total TMNR costs in the i-th variant, PLN/mth,
$K_{T.MWi}$ – TMNR costs of loaders, crusher-screens and belt conveyors in the i-th variant, PLN/mth,
$K_{T.WWi}$ – TMNR costs for haul trucks in the i-th variant, PLN/mth,
$n_{WWi.D}j$ – number of haul trucks in the i-th variant, pcs,
C_{TMNRk} – TMNR amount for the k-th machine operating in a given configuration, PLN/mining equipment, (Table 11),
C_{TMNRW} – TMNR costs for haul trucks, PLN/hour.,
T_e – effective time of haul truck operation during a shift, h,
Z – number of shifts, pcs,
$K_{TWi.Dj}$– haul truck leasing costs in the i-th variant on the j-th process route:

$$K_{T_{Wi.Dj}} = \begin{cases} W_{WUT} \geq 50\% \rightarrow K_{T_{Wi.Dj}} = n_{W_{Wi.Dj}} \cdot Z \cdot T_e \cdot D \cdot C_{TMNR_W} \\ W_{WUT} < 50\% \rightarrow K_{T_{Wi.Dj}} = n_{W_{Wi.Dj}} \cdot Z \cdot T_e \cdot D \cdot C_{TMNR_W} \cdot 50\% \end{cases} \tag{8}$$

For variant W1, these costs are as follows:

$$\begin{cases} K_{T_{W1}} = (n_{W_{W1.D1}} \cdot Z \cdot 50\% + n_{W_{W1.D2}} \cdot Z) \cdot C_{TMNR_W} \cdot T_e \cdot D = 39375 PLN/mth \\ K_{T.W_{W1}} = \Sigma C_{TMNR_k} = 35400 PLN/mth \\ K_{T_{W1}} = K_{T.W_{W1}} + K_{T.M_{W1}} = 74775 PLN/mth \end{cases}$$

Table 12 presents the costs of TMNR costs for haul trucks and other mining equipment in all variants. Fig. 7 contains a comparison of fuel costs for haul trucks and other mining equipment.

The total costs connected with the maintenance and repair of machines for transport routes are characterised by two cost levels, while for other mining equipment, the level of these costs is more diversified. The variant with the lowest TMNR costs is W1. Considering TMNR costs, the analysed quarrying equipment can be divided into two groups: group 1 – up to PLN 100,000/mth – the W1, W2 and W5 variants; and group 2 – over PLN 200,000/mth – the W3 and W4 variants. In addition the costs of the W1 quarrying equipment variant represent only 33% of the TMNR costs for the W4 quarrying equipment variant.

The proportion of the TMNR costs of transport equipment in relation to those of other machines ranges from 33% in the W4 variant to 52% in the W1 variant.

Analysis of the total costs of using mining equipment in quarring

The total costs are a sum of all the costs calculated above – dependences 1–8. These costs are presented in Table 13 and Fig. 8.

$$K_{C_i} = K_{L_{W1}} + K_{T_{W1}} + K_{W_{W1}} + K_{P_{W1}} \qquad \text{[PLN/mth]} \tag{9}$$

where:
K_{CWi} – the total costs of the quarrying equipment in the i-th variant, PLN/mth (Tab.13).

The W1 variant has the lowest total costs among all analysed variants.

Conclusions

The analysis presented in this paper demonstrates the cost structures of using various quarrying equipment configurations for deposits characterised by substandard quality characteristics. Further work should be conducted to determine the component usage costs of modified equipment in quarrying deposits of reduced quality.

The costs of fuel in all analysed quarrying equipment configurations constitute at least 40% of all costs. The second most important component are leasing costs, the share of which

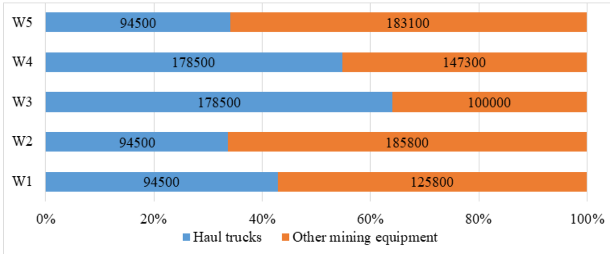

Fig. 6. A comparison of the leasing costs for haul trucks and for other mining equipment making up the process equipment
Rys. 6. Porównanie kosztów leasingu wozideł technologicznych oraz pozostałych maszyn górniczych składających się na układ technologiczny

Tab. 10. The leasing costs in respective equipment configurations
Tab. 10. Koszty leasingu maszyn w poszczególnych układach technologicznych

Leasing costs [PLN/mth]	**W1**	**W2**	**W3**	**W4**	**W5**
Haul trucks	94,500	94,500	178,500	178,500	94,500
Other mining equipment	125,800	185,800	100,000	147,300	183,100
Total	**220,300**	**280,300**	**278,500**	**325,800**	**277,600**

Tab. 11. Quarrying machine leasing costs C_{TMNRk}
Tab. 11. Stawki leasingu maszyn górniczych C_{TMNRk}

Machine	Excavator	Loader	Mobile crusher (diesel)	Mobile crusher (electrical)	Stationary crusher	Grading screen	Belt conveyor
Rate, PLN/mth	5,400	18,000	12,000	5,000	107,300	5,000	3,000

Tab. 12. TMNR costs in respective equipment configurations
Tab. 12. Koszty TMNR maszyn w poszczególnych układach technologicznych

TMNR costs [PLN/mth]	**W1**	**W2**	**W3**	**W4**	**W5**
Haul trucks	39,375	39,375	74,375	74,375	39,375
Other mining equipment	35,400	49,400	143,300	153,700	41,800
Total	**74,775**	**88,775**	**217,675**	**228,075**	**81,175**

Tab. 13. The total costs of quarrying equipment configurations by variant
Tab. 13. Koszty całkowite układów technologicznych w danych wariantach

Scenario I:	**Leasing costs**	**TMNR costs**	**Payroll costs**	**Energy carrier costs**	**Total costs**
	K_L	K_T	K_W	K_P	K_C
	[PLN/mth]	**[PLN/mth]**	**[PLN/mth]**	**[PLN/mth]**	**[PLN/mth]**
W1	220,300	74,775	38,250	222,752	556,077
W2	280,300	88,775	56,250	280,833	706,158
W3	278,500	217,675	74,250	403,601	974,026
W4	325,800	228,075	83,250	473,744	1,110,869
W5	277,600	81,175	56,250	303,795	718,820

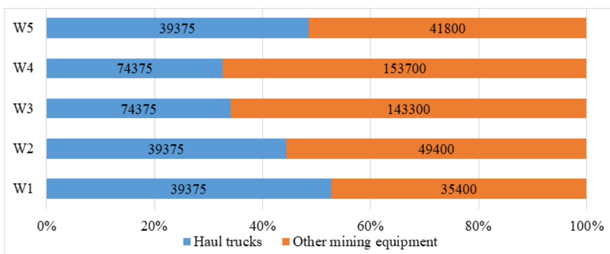

Fig. 7. A comparison of the TMNR costs for haul trucks and for other mining equipment making up the process equipment
Rys. 7. Porównanie kosztów TMNR wozideł technologicznych oraz pozostałych maszyn górniczych składających się na układ technologiczny

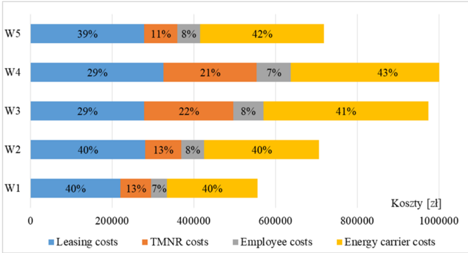

Fig. 8. The proportion of individual costs in the total costs structure of the analysed mining equipment configurations
Rys. 8. Udział poszczególnych kosztów w kosztach całkowitych analizowanych układów technologicznych

ranges from 29% to 40%, depending on the variant. Payroll costs, which represent about 7-8%, have the least influence on the total usage costs of quarrying equipment.

The use of stationary crushers-screens generates lower leasing costs in comparison to total maintenance and repair costs. Mobile crushers-screens are characterised by higher leasing cost shares than TMNR. The share of fuel and power consumption costs and payroll costs is roughly constant and does not depend on the type of the crusher-screen.

This approach can be applied in other quarries with similar extraction profiles.

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Analiza składowych kosztów eksploatacji układów technologicznych do złóż surowców skalnych

W górnictwie surowców skalnych dominują układy technologiczne oparte głównie na transporcie samochodowym, maszynach ładujących oraz przeróbczych. Niezależnie od rodzaju eksploatowanej kopaliny użytecznej mają zbliżoną konfigurację. Racjonalny dobór elementów układu technologicznego z wykorzystaniem środków transportu, maszyn ładujących oraz przeróbczych powinien wynikać z dokładnej analizy aspektów techniczno-ekonomicznych oraz dodatkowo uwzględniać warunki złożowe. Konieczne wydaje się także przeanalizowanie struktury kosztów eksploatacji w relacji do konfiguracji różnych układów odniesionych do warunków górniczo-geologicznych. W celu określenia struktury kosztów parku maszynowego dla analizowanych warunków złożowych zaproponowano pięć konfiguracji układów technologicznych, różniących się od siebie: lokalizacją wstępnego kruszenia, liczbą maszyn, liczbą pracowników (operatorów) oraz długością dróg transportowych. Zagadnienie to jest tym bardziej aktualne gdyż w ostatnich latach pojawia się konieczność wydobycia złóż traktowanych jako złoża o obniżonej jakości.

Słowa kluczowe: układy technologiczne, koszty operacyjne, eksploatacja surowców skalnych, struktura kosztów eksploatacji maszyn