POSSIBILITIES FOR IMPROVING WORK EFFICIENCY OF CONTINUOUS SURFACE MINING SYSTEMS OPERATING IN ROCKS WITH EXCESSIVE DIGGING RESISTANCE

MOŻLIWOŚCI POPRAWY WYDAJNOŚCI PRACY CIĄGŁYCH UKŁADÓW WYDOBYWCZYCH EKSPLOATUJĄCYCH UTWORY O NADMIERNYCH OPORACH URABIANIA

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Long-term strategic planning and scheduling is crucial for successful operation of continuous surface mining projects. It is a complex and multi-objective optimization problem, where the spatial model of the geological and mining characteristics of the deposits is an important issue.

The occurrence of geological structures with excessive digging resistance in the overburden material of the deposits affects the efficiency of the mining system and requires appropriate mine planning and scheduling optimization. This is also the case of South Field Mine, the largest mine that is currently in operation in Ptolemais lignite-bearing basin, Northern Greece, where layers of conglomerates and sandstones with excessive digging resistance are present in the overburden strata.

In this work, the evolution of South Field Mine operation, in relation to the spatial distribution of hard rock materials in the mine is presented. For the strategic planning of the mine, a graphical model has been developed. This model is applied for the selection of the best alternative for the long-term planning of mining operations.

After various in-field tests, the combined use of continuous and conventional mining equipment (i.e. shovels and trucks) was finally decided to be applied for dealing with hard rock formations.

Furthermore, a geostatistical model is presented for spatial interpolation of hard rock materials, based on several drilling data collected from the mine area. Finally, the efficiencies of Bucket Wheel Excavators working in soft and hard rocks are compared based on a statistical analysis of operational data.

Keywords: *strategic mine planning, hard rock materials, kriging, work efficiency, mining equipment*

Strategiczne długoterminowe planowanie i harmonogramowanie mają kluczowe znaczenie dla skutecznej działalności operacyjnej ciągłych układów w górnictwie odkrywkowym. Jest to złożony i wielobiegunowy problem optymalizacyjny, w którym ważnym zagadnieniem jest przestrzenny model geologiczno-górniczy złoża.

Występowanie w nadkładzie struktur geologicznych o nadmiernych oporach kopania wpływa na sprawność systemu wydobywczego i wymaga odpowiedniego planowania oraz optymalizacji harmonogramów. Tak jest również w przypadku kopalni South Field Mine, największej obecnie działającej kopalni węgla brunatnego Ptolemais w północnej Grecji, w której nadkład pokrywają warstwy konglomeratów i piaskowców o znacznych oporach urabiania.

W pracy przedstawiono ewolucję operacji wydobywczych w kopalni South Field Mine w odniesieniu do przestrzennego rozmieszczenia twardych materiałów skalnych. Dla strategicznego planowania kopalni opracowano model graficzny, który wykorzystywany jest do wyboru najlepszej alternatywy dla długoterminowego planu operacji wydobywczych.

Po różnych próbach w terenie, ostatecznie zdecydowano, że do urobienia twardych formacji skalnych zastosowana zostanie metoda kombinowana polegająca na połączeniu ciągłej i cyklicznej metodzie wydobycia.

Ponadto przedstawiono model geostatystyczny do interpolacji przestrzennej materiałów twardych skał, na podstawie kilku danych wiertniczych zebranych z terenu kopalni. Na koniec, wydajność koparek czerpakowych pracujących w miękkich i twardych skałach jest porównywana na podstawie statystycznej analizy danych operacyjnych.

Słowa kluczowe: *strategiczne planowanie wydobycia, twarde materiały skalne, kriging, wydajność pracy, sprzęt górniczy.*

INTRODUCTION

Lignite mining in Greece has a significant contribution to the electricity generation system. The lignite production in 2017 was 37 million tonnes, covering 33% of the electricity generation in the interconnected system of Greece. The majority of the lignite is located in the Ptolemais - Amynteon basin, in the area of Western Macedonia, in northern Greece.

Greek lignite deposits have a multiple-layered structure consisting of several lignite layers separated, mainly, by calcareous and argillaceous waste beds. The necessity of selective mining because of this stratigraphic deposit structure, combined with the requirements for high production rates, was the reason for the application of the continuous surface mining method. The main mining system consists of high capacity bucket wheel excavators, conveyor belts and spreaders. In addition, non--continuous mining equipment (consisting of blast hole drills, shovels, dumpers, loaders, dozers and other auxiliary units) is utilized for mining the hard and semi-hard rock formations, which are encountered in the overburden strata, or for mining deposit formations that are not effectively mined by the continuous mining equipment. Moreover, the non-continuous mining equipment is utilized additionally in the cases that continuous mining equipment is not adequate for handling the required earthmoving works (Roumpos et al., 2014a).

Considering the current technical, economic and environmental conditions of the surface lignite mines operations, the optimization of mine development in combination with the effective utilization of the continuous mining equipment is a very important factor for the viability of the further mining stages (Roumpos et al., 2014b). This factor also is crucial for the effective completion of the deposits exploitation taking into account the more complicated and continuously varying mining conditions and the requirements for the decreased operating cost (Roumpos et al., 2016, 2018). In this context, strategic mine planning is the most important technical aspect of mining activities, shaping the technical plan to be followed in all mine life cycle activities (Dimitrakopoulos, 2018).

Surface mining of multiple-layered lignite deposits often faces the problem of the presence of hard formations, with a particularly unfavorable effect on the productive and economical parameters. In this framework, the mid and short term planning of the parallel operation of continuous and non-continuous mining equipment in mine areas with hard rock formations is crucial for mine production scheduling.

The South Field Lignite Mine is the largest of the three operational surface mines at the Ptolemais area of Lignite Center of Western Macedonia, covering an area of 24 km2 (Fig. 1). The removal of hard formations is done by applying drilling and blasting operations to loosen the hard rock formations. It is then used mobile load-haul equipment to move the blasted material (Agioutantis et al., 2001). The semi-hard formations within the overburden strata that cannot be excavated by BWEs are loaded by shovels without any blasting.

The existence of hard rock formation with high cutting resistance results affects the production rate of the main continuous mining equipment. Therefore, the identification of the spatial distribution of hard formations with excessive digging resistance within the mine area is crucial for the appropriate long and short-term mine planning and design activities.

This paper investigates the possibilities for improving work efficiency of the continuous mining equipment in relation to strategic planning of the mine. The analysis is based on a strategic mine development model as well as on the geostatistical estimation of hard formations. The efficiency of the mining equipment is analyzed regarding the gradual transition of the mine to a new belt conveyors distribution point Geological setting

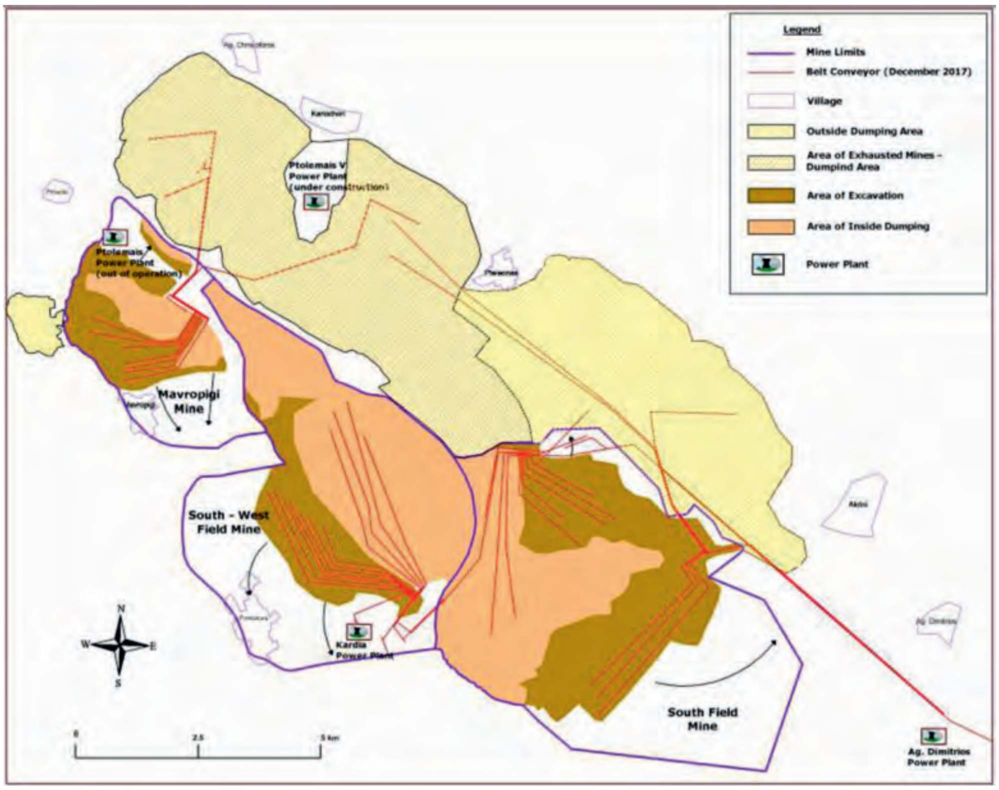


Fig. 1. Ptolemais lignite basin and South Field mine (December 2017)
Rys 1. Zagłębie węgla brunatnego Ptolemais wraz z kopalnią South Field (grudzień 2017)

GEOLOGICAL SETTING

The South Field Mine forms the southern boundary of the total Ptolemais mining area (Fig. 1). It extends approximately 8 km towards the northwest and the southeast. Its SW-NE extension ranges between approximately 5 km in the northwest and 4 km in the southeast.

The deposit of the South Field is divided into partly narrow faulted blocks by several faults, which mainly strike in a NW--SE to WNW-ESE direction and mostly consist of down thrown and, to a lesser extent, of up thrown faults with slight faulting in the underlying seams. The overall thickness of the lignite-bearing series amounts to approximately 20 - 30 m in the southeast and northeast of the mining field, while towards the west and north-west it increases to approximately 70 - 100 m in the present opencast mine slope. In the areas of the western and eastern final slopes, the thicknesses of the split seams partly decrease over a short distance, with the intercalations increasing in thickness at the same time.

The overlying strata thickness ranges from approximately 70 – 100 m at the present mine rim to up to approximately 200 m in the southern part of the mining field. The layer series is composed of finely clastic, sandy clays and calcareous, clayey marls with coarsely clastic, marly sands, sandy gravels and pebbles (Figs. 2a, 2b & 2c).

Water outlets from the coarsely clastic sediments have been observed in the opencast mine. Furthermore, these layers locally incorporate consolidated intercalations seriously impeding mining operations, which principally consist of conglomerates, sandstone and calcareous marl (Anastopoulos & Koukouzas, 1972).

MINING OPERATIONS AND EQUIPMENT

The continuous mining method, which employs bucket wheel excavators (BWEs), conveyors and stackers, is the principal mining method used in South Field mine. Combining the high extraction rales of BWEs (when used in soft material) and the continuous flow of material through conveyor systems and spreaders to the dumping areas, high production rates can be achieved.

The South Field mine has been divided into 11 excavation sectors (Fig. 3). Considering the flow of the excavated material in the South Field continuous mining system, the equipment can be divided into three subsystems (Fig. 3): (a) the excavating (loading) subsystem with two parts, one in Sector 6 and one in Sector 7, (b) the two distribution points and conveying subsystem and (c) the outside (three spreaders) and inside (three spreaders) dumping subsystem (Agioutantis & Kavouridis, 1995).

The original lignite deposit in the area was estimated at 1.2 billion tons of lignite. Mining operations commenced in August 1979 and the continuous mining excavations equipment currently operates on nine benches (five in Sector 6 and four in Sector 7).

After one year of mine operation it was clear that the extent of hard and semi-hard rock formations is much larger than the expected based on the results of the deposit exploration study.

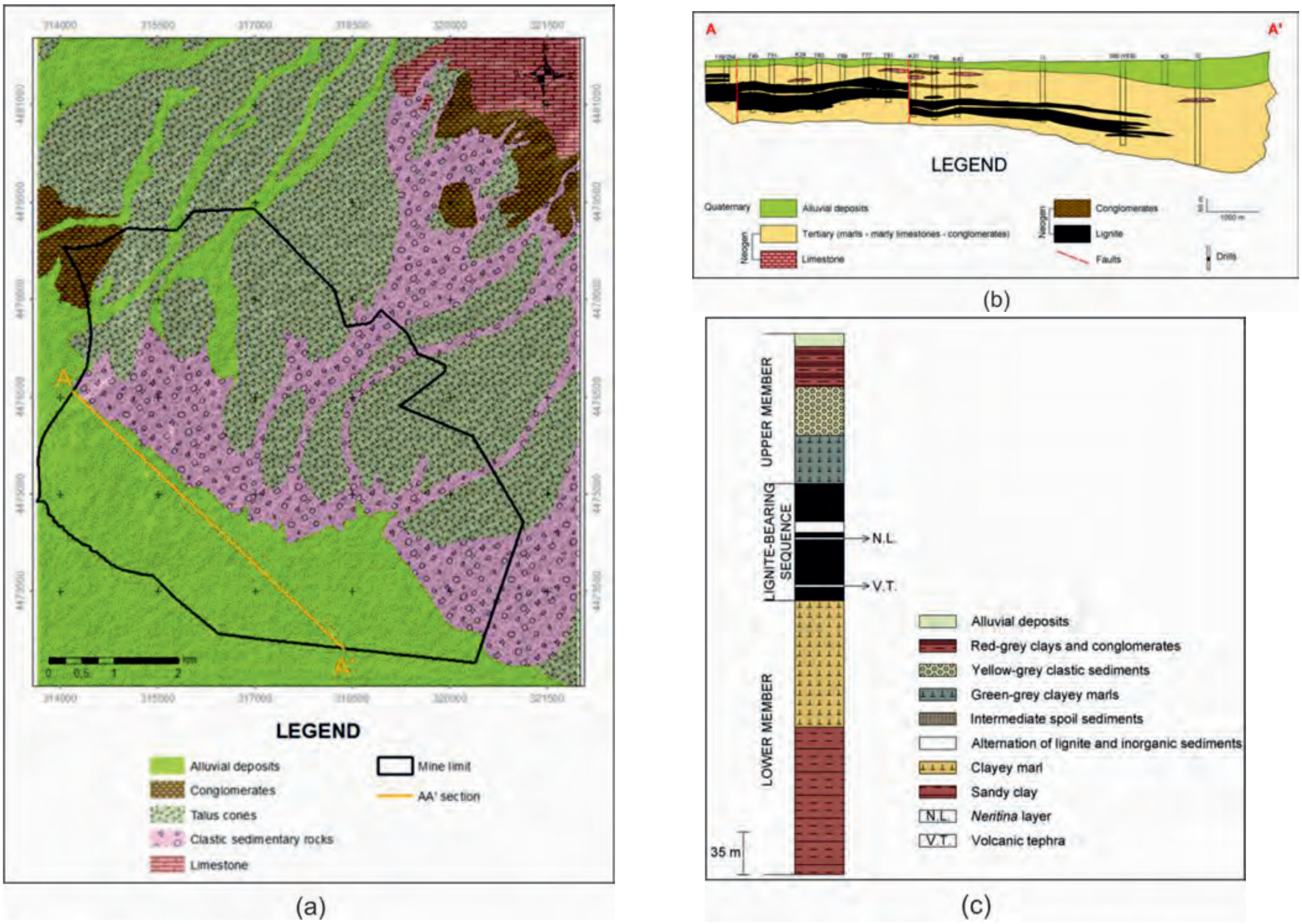


Fig. 2. Geological setting of the South Field mine, (a) Geological map, (b) Typical geological section A-A', (c) Stratigraphic column

Rys. 2. Charakterystyka geologiczna South Field Mine, (a) mapa geologiczna, (b) typowy przekrój geologiczny A-A', (c) Przekrój stratygraficzny

After various in-field tests, the combined use of continuous and conventional mining equipment (i.e. shovels and trucks) was finally decided to be applied for dealing with hard rock formations. The selected method included the splitting of the overburden strata into benches of relatively lower height than the height which was proposed in the initial study. This development simplified the positioning of hard rock formations and increased the efficiency of the mine operation. In addition, diesel-engine earth moving equipment of non-continuous operation for the haulage of hard rocks was installed independently from the continuous mining systems (Kavouridis et al, 2008).

The complex and continuously varying conditions in the mine require a close collaboration between continuous and non--continuous mining systems. Because of the dynamic character of the mining conditions, it is also necessary to inspect and modify the operating parameters of the mine very often.

Model of mine development

The alternatives for the strategic South Field mine development that were analyzed after the initial box-cut of the mine (Rheinbraun Engineering and Public Power Corporation of Greece, 1996) are shown in Fig. 4. These alternatives were based on the sequence of mining in combination with the relocation of the belt distribution point and the removal of hard rock material (especially at the eastern perimeter of the mine).

The decision making for the concept of the South Field development, considering the alternatives of Fig. 4, was based on the main following parameters:

(a) Volume of the outside dump

(b) Time evolution of hard rocks excavations

(c) Time evolution of stripping ratio (waste to lignite)

(d) Capital and operating cost

(e) Relocation of technical works or other technical and spatial parameters

For the determination of the above parameters for each alternative, a production schedule graphical model was developed. The model is based on the technical data for the excavation and the corresponding inside dumping sectors of the mine. For the design of these sectors, the deposit characteristics as well as the geotechnical data are used. The quantitative data of the excavation sectors for the alternative (v), which is closer to the followed mining development sequence shown in Fig. 3, are presented in Tables 1 (data per sector) and 2 (accumulated data). Fig. 5 shows the graphical representation model for this alternative (v), based on the data of Tables 1-2 as well as on the corresponding data for the inside dumping sectors.

On the x-axis of Fig. 5 the accumulated lignite reserves are shown. On the y-axis, positive volumes represent the excavation site of the mine and negative volumes correspond to the dumping site of the mine. The first of these volumes is the accumulated lignite volume (Lign. Vol.). The total waste excavations can be determined from the accumulated total excavations (T.E.Min.) and "Lign. Vol.".

The accumulated total excavations (T.E.Min.) are then converted to the minimum dump volume requirements (D.V.Min.) taking into account the swell factor. The dump volume is further increased by the deposition of ash (and possibly other materials to be dumped in the mine). The dump space inventory on the inside dump (Dmp Invent.) of the mine is determined by deducting the accumulated volume of the inside dump sectors from the minimum dump volume requirements (D.V.Min.). The minimum of this graph (Dmp Invent.) is the minimum outside dump volume.

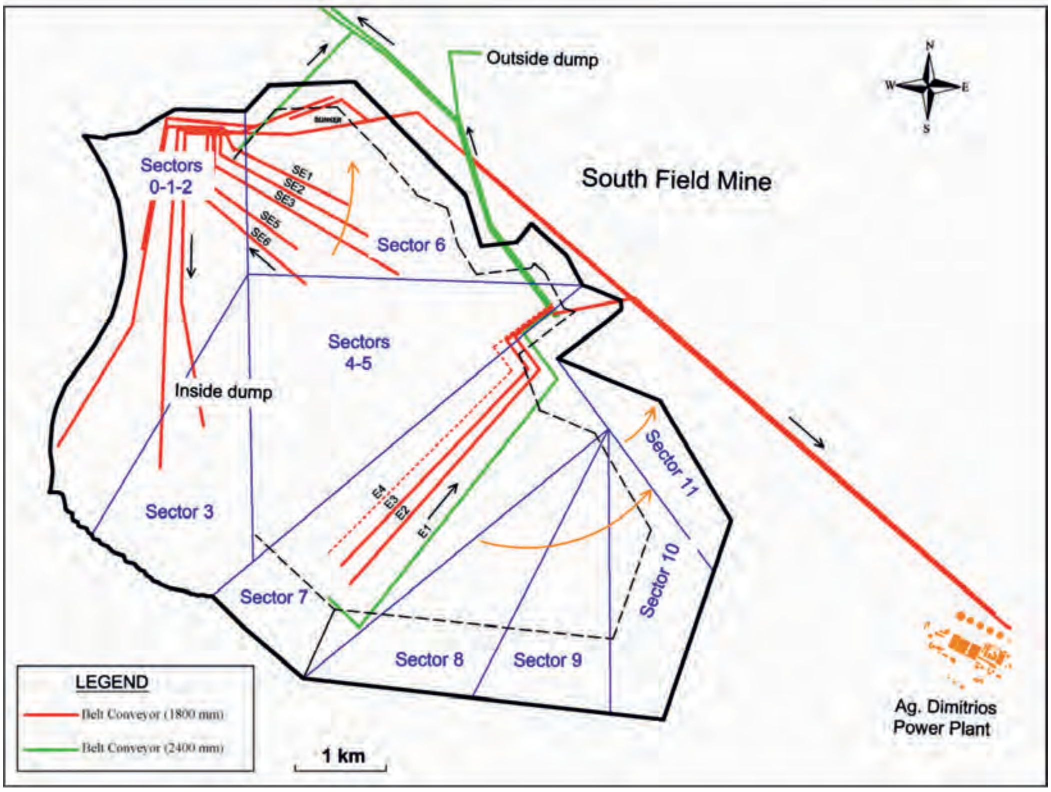


Fig. 3. South Field mine: excavations, sectors and current mine position (June 2018)
Rys. 3. South Field mine: eksploatacja, sektory oraz aktualny zarys wyrobiska (czerwiec 2018)

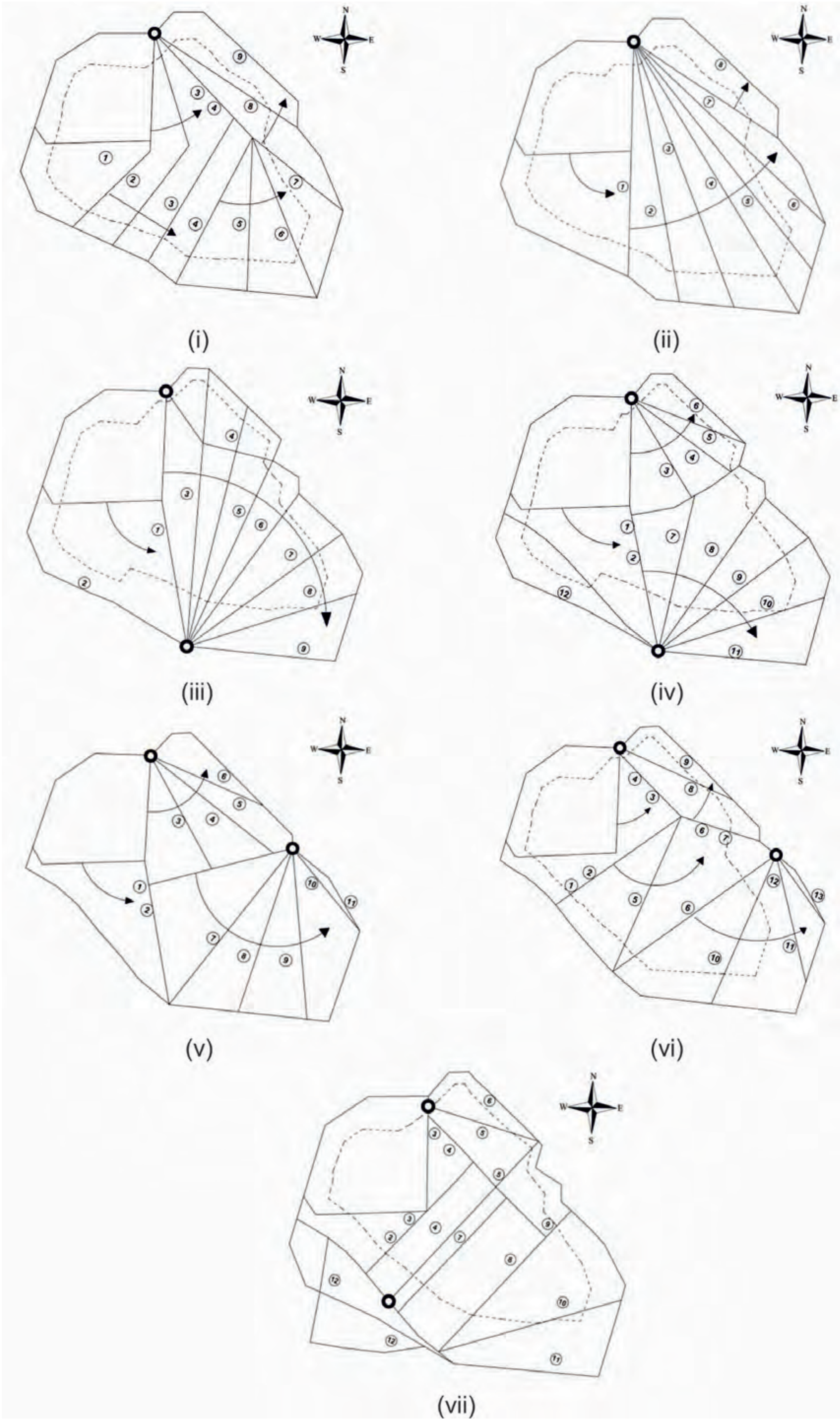


Fig. 4. Alternatives for strategic South Field mine development
Rys. 4. Alternatywy strategicznego rozwoju kopalni South Field

The maximum possible dump volume (D.V.Max.) can be determined by adding the accumulated volume of the inside dump sectors to the known volume of the outside dump. The minimum dump volume (D.V.Min) and the maximum dump volume (D.V.Max.) are equal at the end of sector 10, and they must be equal ccording to the applied algorithm. The mine has reached then the so called critical position. The maximum dump volume (D.V.Max) can be converted to the maximum total excavation (T.E.Max).

The ash component in the maximum dump volume is to be converted into the corresponding lignite volume and the waste is again converted to solid ground. The maximum total excavation (T.E.Max) and the minimum total excavation (T.E.Min.) are also equal at the end of the sector 10, where the space inventory of the inside dump (Invent.) passes its minimum. The mine has reached its critical position. The dump slope system and the excavation front correspond to the sector slope at the end of sector 10.

The maximum total excavation has been determined based on dump space considerations. There is, however, another restriction to be observed. The minimum total excavation (T.E.Min) can only be exceeded by pre-stripping overburden. Correspondingly, the difference between the minimum total excavation (T.E.Min) and the maximum total excavation (T.E.Max.) must not be more than the remaining accumulated overburden at the end of each of the sectors. By adding this figure the maximum pre-stripping possibilities can be determined. As long as the maximum total excavation is less than the maximum pre-stripping possibilities, the maximum of the total

Tab. 1. Quantitative data for excavation sectors of alternative (v)
Tab. 1. Dane ilościowe dla sektorów wydobywczych wyrobisk alternatywnych (wariant v).

Sector	Lignite		Waste				Total Excavation		
	Weight	Volume	Intercalations	Overburden	Hard rocks	Total	Min.	Prod.	Max.
	[Mt]	[Mm³]	[Mm³]	[Mm³]	[Mm³]	[Mm³]	[Mm³]	[Mm³]	[Mm³]
1	179.6	141,1	80.4	291.7	57.4	429.5	570.6		
2	53.8	42.4	21.1	72.5	4.3	97.9	140.3		
3	57.4	45.5	18.1	104.4	47.2	169.2	215.2		
4	39.5	31.1	11.1	84.8	64.2	160.2	191.3		
5	46.3	35.9	17.9	66.7	81.2	165.8	201.7		
6	27.8	21.9	14.3	58.4	61.5	134.2	156.1		
7	120.5	95.2	37.3	465.6	74.7	577.6	672.8		
8	96.5	76.9	42.6	444.6	38.5	525.7	602.6		
9	68.8	55.1	27.7	389.8	29.2	446.7	501.8		
10	69.2	55.6	20.8	553.9	37.3	612.0	667.6		
11	16.8	13.4	6.5	105.9	7.3	119.7	133.1		

Tab. 2. Quantitative accumulated data for excavation sectors of alternative (v)
Tab. 2. Skumulowane dane ilościowe dla sektorów wydobywczych wyrobisk alternatywnych (wariant v).

Sector	Lignite		Waste				Total Excavation		
	Weight	Volume	Intercalations	Overburden	Hard rocks	Total	Min.	Prod.	Max.
	[Mt]	[Mm³]	[Mm³]	[Mm³]	[Mm³]	[Mm³]	[Mm³]	[Mm³]	[Mm³]
0-0	0.0	0.0	0.0	0.0	0.0	0.0	0,0		586.3
0-1	179.6	141.1	80.4	291.7	57.4	429.5	570.6		917.1
0-2	233.4	183.4	101.6	364.1	61.8	527.5	710.9		1048.8
0-3	290.8	229.0	119.7	468.5	109.0	697.2	926.1		1179.4
0-4	330.3	260.1	130.8	553.3	173.2	857.3	1117.4	1.150.0	1265.5
0-5	376.6	295.9	148.7	620.0	254.5	1023.2	1319,1		1504.8
0-6	404.4	317.9	163.0	678.4	316.0	1,157.4	14752		1666.6
0-7	524.9	413.1	200.3	1144.0	390.6	1734.9	2148.0		2226.5
0-8	621.4	490.0	242.9	1588.6	429.2	2260.7	2750.6		2799.4
0-9	690.1	545.1	270.6	1978.3	458.4	2707.3	3252.4		3284.5
0-10	**759.3**	**600.7**	**291.4**	**2532.2**	**495.7**	**3319.3**	**3920.0**		**3920.0**
0-11	776.2	614.1	297.8	2638.1	503.0	3439.0	4053.1		4140.4

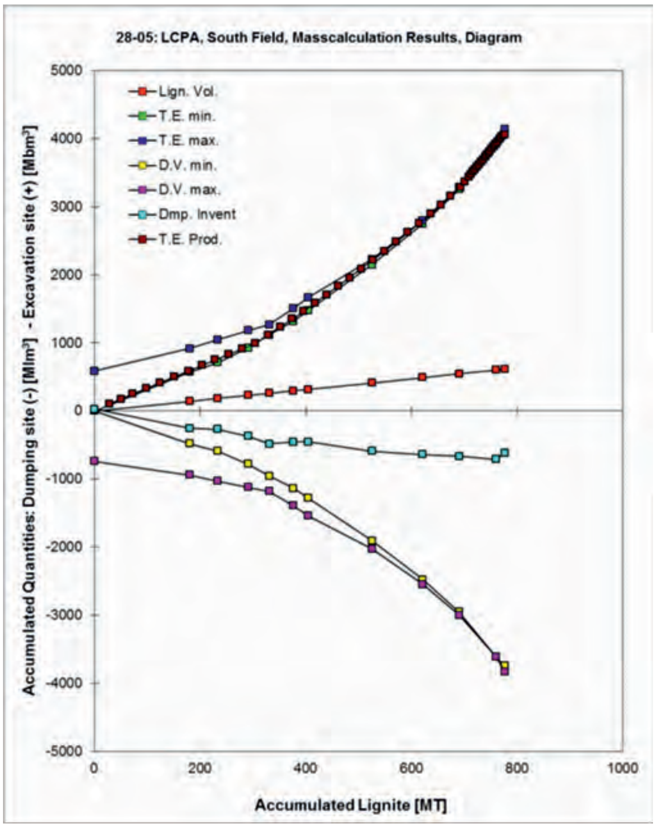


Fig. 5. Graphical model for alternative (v) of South Field mine development
Rys. 5. Graficzny model alternatywny rozwoju kopalni South Field – wariant v

excavation represents the upper limit of the total excavation and vice versa.

According to the described model, the production schedule for an opencast mine with inside dumping must be kept between the maximum total excavation (T. E. Max) and the minimum total excavation (T. E. Min).

The long-term required excavations for the removal of hard rocks are determined by the production scheduling of the described model. For a detailed planning of hard rock excavations, the model of the spatial distribution of hard formations is needed in combination with (a) the geometrical characteristics of the excavation benches, (b) the suitable installation of the continuous and non-continuous mining equipment into mine benches in relation to the corresponding operational availability and work efficiency, (c) the fleet management of the non-continuous mining equipment, (d) the planning of waste dumping considering also the contribution of the hard rocks to the stability of the dumping slopes.

Efficiency of mining equipment

For the analysis of the work efficiency of BWEs operating in the South Field mine the operational data of the period 2010--2017 were used, investigating the gradual transition of the mine to a new belt conveyors distribution point, from Sector 6 to Sector 7. Roumpos and Nalmpanti (2012) described the process of the step by step relocation, based on production scheduling and project management techniques. In this framework, the operational availability and flexibility of the continuous and non-continuous mining equipment were considered.

Fig. 6 presents the type of the BWEs, the corresponding benches as well as the operating areas in Sectors 6 and 7 at this time period. In the period 2010-2013 the BWEs in Sector 6 operated in the benches 1A, 1B, 2A, 2B, 3, 4, 5, 6A and 6B while, since 2014, the BWEs operated at the benches S1-S6. The adjustments to the new benches were derived from the decreasing depth of the mine in Sector 6, in combination with the transportation of the equipment to Sector 7.

The main parameters of the BWEs for the statistical analysis include the utilization factor (nu, %), the time operating factor (nt, %), expressing the operating time as a percentage of the calendar time, and the load factor (nl,%), comprising the capacity reductions related to the actual conditions at the excavation site. The relation of these parameters is describ by Eq. (1). The utilization factor is used to calculate the effective capacity of BWEs according to Eq. (2).

$$n_u = n_t \cdot n_l \quad (1)$$

$$Q_{eff} = Q_{th} \cdot n_u \ (m^3_b/h) \quad (2)$$

Where, Q_{th}: theoretical capacity (m^3_l/h) and Q_{eff}: Effective capacity (m^3_b/h) (l: loose material, b: bank (in situ) material).

The main research questions of the analysis include the investigation of the operating efficiency parameters regarding the type and the location of the BWEs in relation to the spatial distribution of the hard formations.

Fig. 7 presents the utilization factors of all BWEs of South Field mine for the period 2010-2017. The results demonstrate the considerable effect of the location on the utilization factor. This factor presents also spatial variability considering the differences related to different benches of a Sector or to different Sectors 6 and 7.

For a detailed analysis, the main efficiency factors of all BWEs were examined.

Fig. 8 presents the operating data for BWE SE1 (Ta-SRs 2000/5 x 32) and the contract works as a percentage of the total excavations in the corresponding benches for the period 2010-2017.

The statistical analysis showed that there was a significant correlation between contact works and efficiency factors of a BWE operating in the same bench. This correlation is interesting because by defining the areas of non-continuous mining operations, based on the spatial distribution of hard rocks, there is a possibility to improve the availability and efficiency of continuous mining equipment. This is also in a good agreement with the practice of splitting the overburden strata into more benches or changing the geometrical characteristics of the benches.

This mining design improves the process of the hard rock formations removal and increases the efficiency of the mine operation. In addition, the in situ mining and geological conditions are related to the work efficiency of the BWEs.

A further investigation is needed regarding the downtime factors of BWEs, the conveying and dumping subsystems, as well as the as well as in situ specific conditions.

Geostatistical estimation of hard formations in Sector 7

Geostatistical estimation is used to interpolate the value

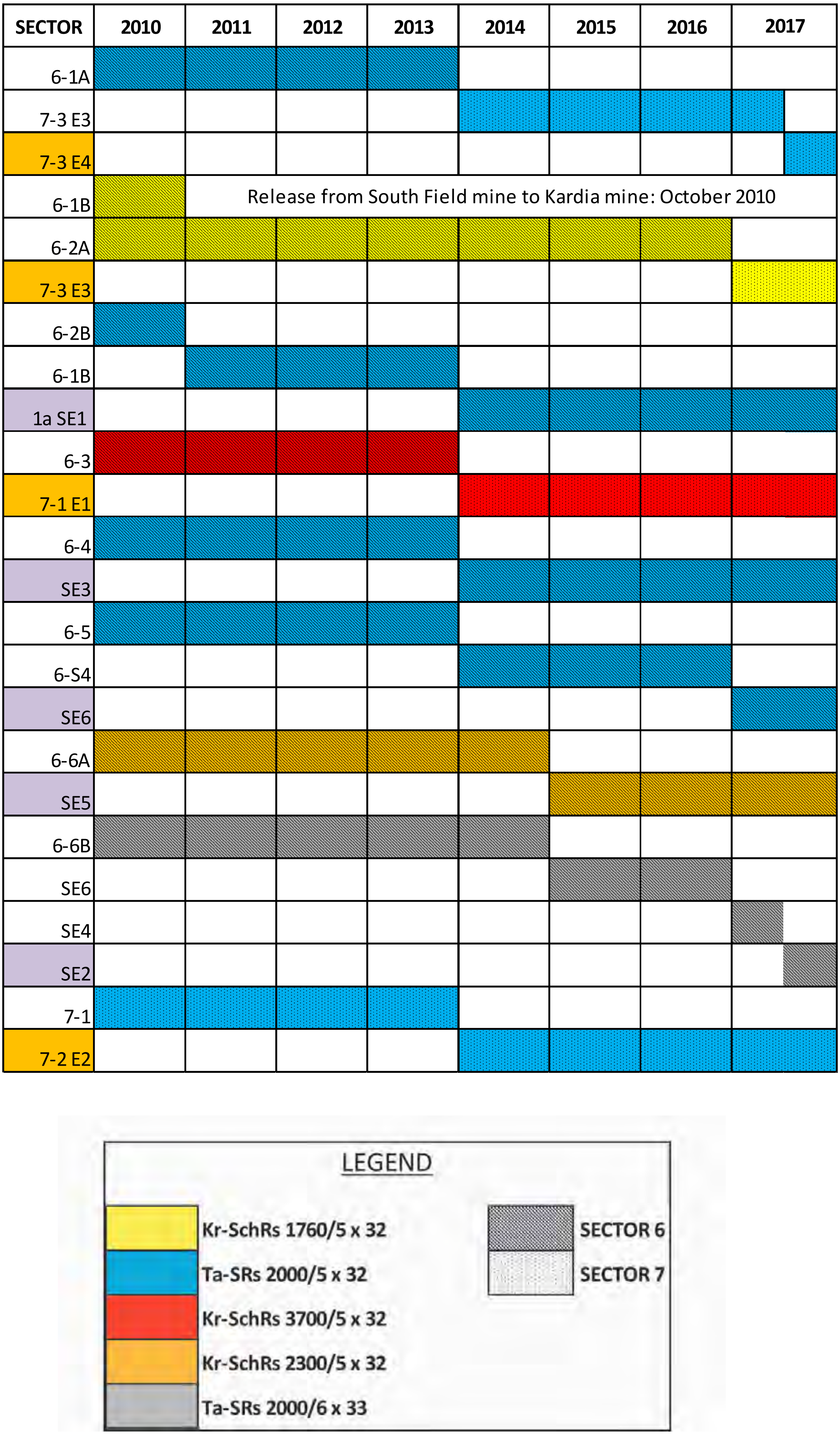


Fig. 6. Location of bucket wheel excavators in Sectors 6 & 7 (period 2010-2017)
Rys. 6. Lokalizacja wielonaczyniowych koparek kołowych w sektorach 6 i 7 (lata 2010-2017)

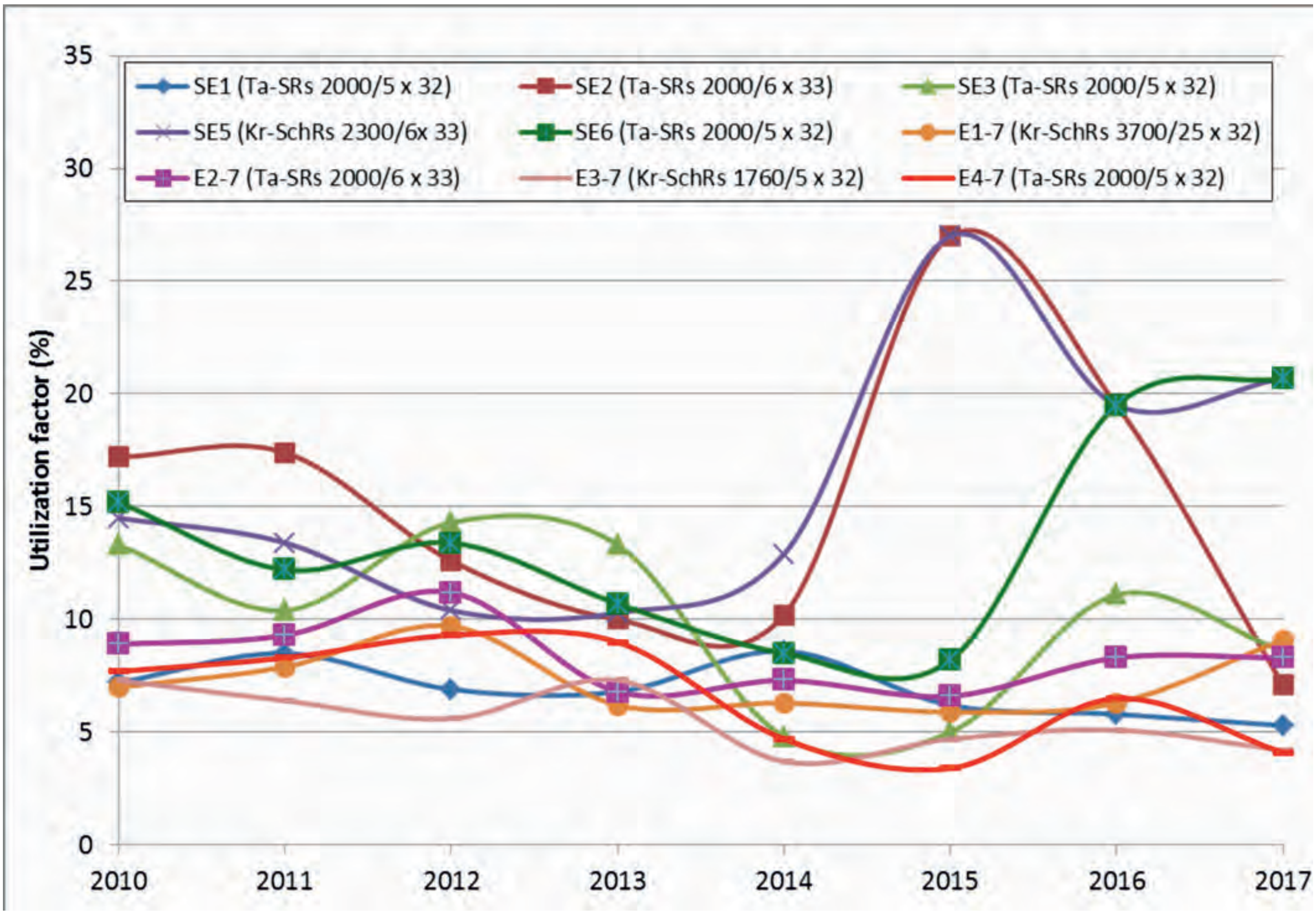


Fig. 7. Utilization factors of all BWEs of South Field mine for the period 2010-2017
Rys. 7. Współczynniki wykorzystania poszczególnych wielonaczyniowych koparek kołowych w kopalni South Field w latach 2010-2017

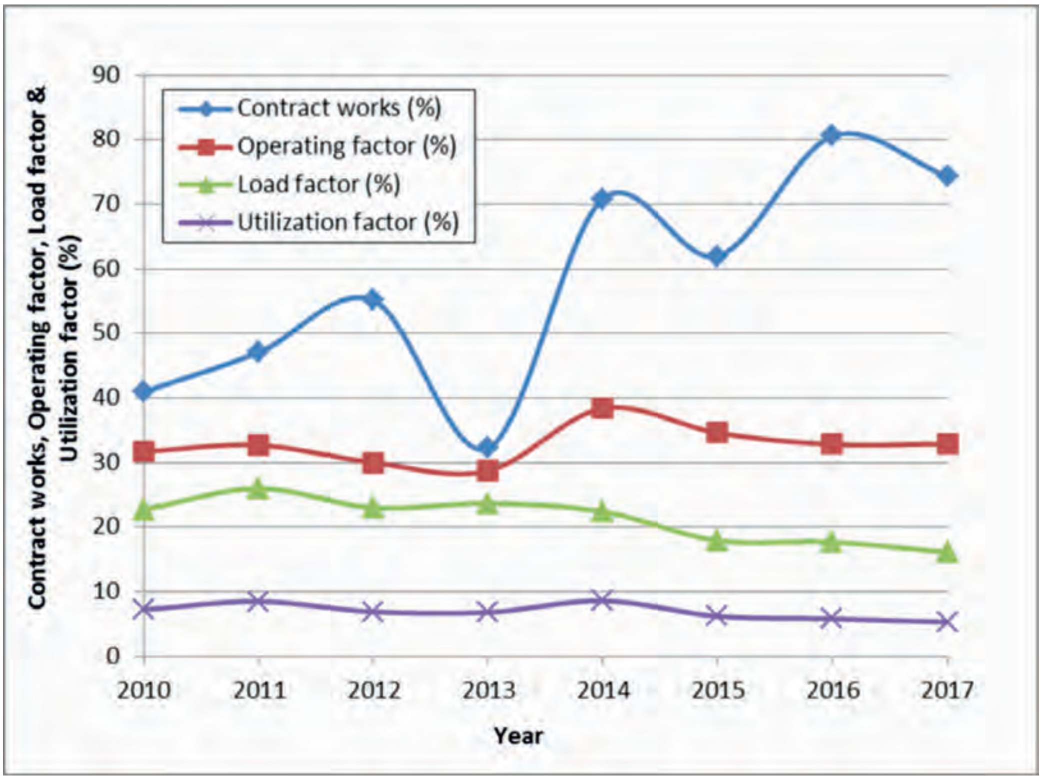


Fig. 8. Operating data for BWE SE1 (Ta-SRs 2000/5 x 32) and contract works in the corresponding benches for the period 2010-2017
Rys. 8. Dane operacyjne dla koparki BWE SE1 (Ta-SRs 2000/5 x 32) oraz prace operatorów zewnętrznych na tych samych piętrach w latach 2010-2017

of a given attribute at a given location, by minimizing the error and bias of the estimate. It facilitates quantification of the spatial features of geological parameters and enables spatial interpolation. Geostatistical models provide a probabilistic framework for data analysis that builds on the spatial dependence between observations (Modis & Sideri, 2015). The aim of the geostatistical analysis performed here, is to estimate the best spatial distribution of the hard formations in the South Field mine (Fig. 10).

Ordinary kriging (Goovaerts, 1997; Deutsch and Journel, 1997) is a local estimation technique which provides the best linear unbiased estimator of the unknown characteristic studied. This limitation to the class of linear estimators is quite natural, since it means that only the second-order moment of the random function (i.e., the covariance or variogram) is required and in general, it is possible in practice to infer the moment.

Practically in order to estimate the value of a variable Z_0 in a point x0 of the space-time, using a set of values of the same parameter measured on n near points x_α (α=1, n), a linear combination of the measurements is formed:

$$Z_0^*(x_0)=\sum_{\alpha=1}^{n}\lambda_\alpha^0 Z_0(x_\alpha) \tag{3}$$

where the vector of the coefficients is $\left\{\lambda_\alpha^0\right\}$ calculated in order to have an unbiased estimator and to minimize the difference between the unknown value on the estimation point and the kriged value on the same point. Minimization takes into account the spatial variability of the parameter expressed by the variogram function $\gamma_0(h)$, which is the semivariance of the parameter increment with respect to distance *h*:

$$2\gamma_0(h) = \mathrm{var}\left[Z_0(x+h)-Z_0(x)\right] \tag{4}$$

A variogram model is adjusted on experimental variograms by means of a fitting operation. Ordinary kriging is characterized by a measure of its accuracy, which is the estimation error variance. This is useful to define estimation uncertainty and to outline areas that need a supplemental sampling.

The preparatory works were carried out concerning the investigation of mining conditions in relation to spatial distribution of the hard rock formations in the area of South Field Mine. The litho-stratigraphic units within the overburden were also analyzed.

The original drill-holes data were evaluated in combination with the above geological data. The interpolation results of the hard materials distribution in Sector 7 regarding the first two benches are shown in Fig. 9.

According to the kriging estimation it is concluded that the hard formations are located in the NE area of bench 1 with a thickness of more than 10 m and in the NE and SW areas of bench 2 with a thickness exceeding 8 m and 4 m respectively.

Finally, the results of the above model were validated based on the real data of the period 2010-2017.

Conclusion

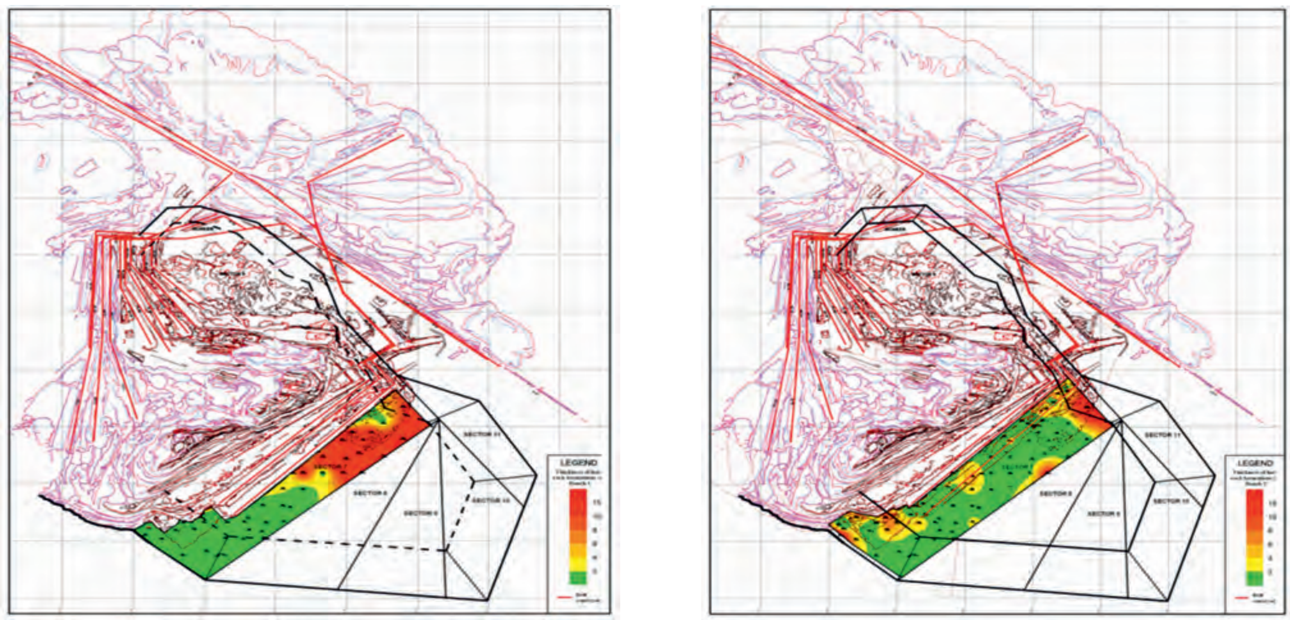
The information about the size and distribution of hard rock formations in the overburden strata is critical for the successful mine planning and development and equipment selection.

The initially data resulted to decisions that did not meet the demanded production and did not fit to the real operating conditions. This fact caused considerable delays in mine opening and development.

The revision of the mine development plans included changes in the number of benches in overburden strata and combined operation of non-continuous earth moving equipment (i.e. shovels and trucks) with the continuous mining systems.

The graphical model which has been developed could be applied as a useful tool for the strategic planning of a continuous surface mine, incorporating data for the spatial distribution of hard formations.

The BWE efficiency factors present spatial variability con-



(i) Bench 1 (ii) Bench 2

Fig. 9. Spatial distribution of hard rock materials in benches 1 and 2 of Sector 7
Rys. 9. Rozkład przestrzenny twardych materiałów skalnych w piętrach 1 i 2 Sektora 7

sidering the differences related to different benches of a Sector or to different Sectors.

The spatial interpolation model of hard rock materials can be applied to improve the work efficiencies of Bucket Wheel Excavators working in soft and hard rocks.

The statistical analysis showed that there was a significant correlation between contact works and efficiency factors of a BWE operating in the same bench. In addition, the in situ mining and geological conditions are related to the work efficiency of the BWEs.

A further investigation is needed regarding the downtime factors of BWEs, the conveying and dumping subsystems, as well as the as well as in situ specific conditions.

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