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THE METHOD OF VALIDITY EVALUATION OF HARD COAL EXCAVATION IN RESIDUAL SEAM PARTS

METODA OCENY ZASADNOŚCI EKSPLOATACJI RESZTKOWEJ PARCELI POKŁADU WĘGLA KAMIENNEGO

The excavation of residual seam parts should be justified by positive assessment of the purposefulness, technical feasibility and economic effectiveness. The results of the profitability evaluation are crucial in a decision making process. The excavation of residual seam parts, even if it is possible from a technical point of view, should not be implemented if it is economically inefficient or when accompanied by a very high risk of non-recovery of invested capital resources. The article presents the evaluation method of possibilities of excavating hard coal from residual seam parts, and the example of its use in one of collieries in the Upper Silesian Coal Basin. Working in line with the developed method, allows to indicate the variant of residual seam part exploitation, which is feasible to implement from a technical point of view, and which is characterized by the highest economic effectiveness and lowest risk.

Keywords: excavation of hard coal, residual seam parts, evaluation method

W obszarach górniczych śląskich kopalń znajdują się zasoby węgla kamiennego pozostawione w przeszłości w resztkowych parcelach. Obecnie kopalnie rozważają możliwość ich eksploatacji m.in. w celach przedłużenia swojej żywotności, ograniczenia strat zasobów węgla, czy poprawy warunków utrzymania wyrobisk.

Podjęcie decyzji o eksploatacji resztkowych parceli, oprócz jej celowości, powinno być uzasadnione pozytywną oceną technicznej wykonalności (m.in. według kryteriów bezpiecznego prowadzenia eksploatacji złoża węgla kamiennego) oraz ekonomicznej efektywności. Szczególnie duże znaczenie ma ocena ekonomicznej efektywności. Eksploatacja resztkowych parceli, nawet jeśli jest wykonalna pod względem technicznym, nie powinna być podjęta jeśli jest ekonomicznie nieefektywna lub jeśli towarzyszy jej zbyt wysokie ryzyko osiągnięcia strat i nieodzyskania zainwestowanych nakładów finansowych.

W artykule przedstawiono, w ujęciu teoretycznym i praktycznym, metodę oceny zasadności eksploatacji resztkowej parceli pokładu węgla kamiennego z uwzględnieniem kryteriów ekonomicznych i technicznych, która została opracowana dla kopalń Górnośląskiego Zagłębia Węglowego. Metoda obejmuje pięć wzajemnie ze sobą powiązanych etapów.

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W 1. etapie należy ocenić techniczne możliwości eksploatacji resztkowej parceli, na podstawie informacji o jej parametrach geoinżynieryjnych, które dotyczą miąższości pokładu węgla, występowania zagrożeń naturalnych (tąpaniami, metanowego, wodnego, wyrzutem gazów i skał) oraz konieczności ochrony powierzchni. Przyjęto, że nie powinna być prowadzona eksploatacja resztkowej parceli zakwalifikowanej do II i III stopnia zagrożenia tąpaniami, IV stopnia zagrożenia metanowego, II i III stopnia zagrożenia wodnego, I, II i III stopnia zagrożenia wyrzutem gazów i skał oraz zlokalizowanej pod bardzo ważnymi obiektami powierzchniowymi, wrażliwymi na osiadania oraz naprężenia podłużne i poprzeczne. Przyjęto również, że nieuzasadnione jest eksploatowanie resztki o miąższości mniejszej od 1,5 m. Zdaniem autorów, wymienione warunki stanowią techniczne ograniczenia eksploatacji resztkowej parceli.

W 2. etapie należy wskazać możliwe warianty eksploatacji resztkowej parceli. Mogą się one różnić systemem eksploatacji, wyposażeniem technicznym (np. typem kombajnu, obudowy), sposobem finansowania wyposażenia technicznego (np. środki własne, kredyt, leasing), czy liczbą przodków eksploatacyjnych. Przyjęto, że wybór systemu eksploatacji resztkowej parceli zależy od jej parametrów geoinżynieryjnych, takich jak miąższość i nachylenie pokładu węgla, zagrożenia naturalne (tąpaniami, metanowe, wodne, wyrzutem gazów i skał) oraz warunki stropowe i spągowe. Ważne znaczenie w wyborze systemu eksploatacji mają także preferencje kopalni, które mogą być związane np. z doświadczeniem załogi, czy posiadanym wyposażeniem technicznym, które można wykorzystać do eksploatacji parceli.

W 3. etapie należy przeprowadzić wstępną selekcję przedstawionych wariantów eksploatacji resztkowej parceli, na podstawie oceny ich ekonomicznej efektywności. Przyjęto, że ocena ta zostanie oparta na podejściu deterministycznym, a w szczególności na analizie zdyskontowanych przepływów pieniężnych *DCF* (wzór 1) oraz kryterium wartości zaktualizowanej netto *NPV* (wzór 6). Założono, że eksploatacja parceli zgodnie z określonym wariantem jest możliwa jeśli jest efektywna ekonomicznie, tj. gdy $NPV > 0$.

W 4. etapie, ze względu na niepewność co do warunków oraz rezultatów eksploatacji resztkowej parceli, należy dokonać pomiaru i oceny efektów ekonomicznych z uwzględnieniem ryzyka ich nieuzyskania. Do tego celu zaproponowano podejście probabilistyczne oparte na symulacji Monte Carlo. W jej toku ustala się rozkłady prawdopodobieństwa i dystrybuanty określonych czynników ryzyka (zmiennych losowych), a następnie na podstawie przeprowadzonych symulacji zostają ustalone wartości tych czynników oraz odpowiadający im wynik *NPV*. Przyjęto, że miarą ekonomicznej efektywności analizowanych wariantów eksploatacji resztkowej parceli jest wartość oczekiwana μ_{NPV} (wzór 7), natomiast miarą ryzyka jest odchylenie standardowe σ_{NPV} (wzór 8). Wyniki pomiaru ryzyka pozwalają na dokonanie jego oceny, którą należy oprzeć na stosunku μ_{NPV} oraz σ_{NPV}, określanym jako współczynnik zmienności CV_{NPV} (wzór 9).

Zastosowanie opracowanej metody umożliwia wskazanie wariantu projektu eksploatacji resztkowej parceli, który jest optymalny pod względem ekonomicznej efektywności i ryzyka, przy uwzględnieniu technicznych warunków ograniczających. Sposób postępowania w tym zakresie opisano w 5. etapie metody. Przyjęta funkcja kryterium optymalizacji opiera się na współczynniku zmienności CV_{NPV}. Wartość tego współczynnika jest również podstawą podjęcia decyzji dotyczącej eksploatacji ocenianej parceli (Tab. 1). W metodzie nie określono ogólnych norm decyzyjnych, gdyż te same wyniki oceny CV_{NPV} dla dwóch różnych decydentów mogą oznaczać szansę lub zagrożenie i mogą mieć wpływ na pozytywną lub negatywną decyzję. Z tego względu wskazano jedynie na potrzebę arbitralnego opracowania tych norm w odniesieniu do sytuacji konkretnej kopalni.

W artykule przedstawiono sposób wykorzystania opracowanej metody w jednej z kopalń Górnośląskiego Zagłębia Węglowego. Postępowanie według przyjętych w metodzie etapów umożliwiło opracowanie ośmiu możliwych do zrealizowania wariantów eksploatacji ocenianej parceli, a następnie wskazanie wariantu optymalnego. Uzyskane informacje o tym wariancie stanowiły podstawę podjęcia decyzji o eksploatacji tej parceli.

Słowa kluczowe: eksploatacja węgla kamiennego, resztkowe parcele, metoda oceny ekonomicznej efektywności

1. Introduction

Geological and mining conditions in Silesian collieries, and especially regular deposition of strata, relatively large seams' thickness, their slight slope, favourable tectonics, and big parcels planned to exploit, resulted in prefering a longwall system as nearly the only system for the exploitation of hard coal. This system requires to divide an exploitation panel into parcels of rectangular shape. As a result the parts of exploitation panels were not excavated and they were named as residual parcels (Turek & Lubosik, 2008a).

Hard coal resources, left in residual deposits, have significant importance from an economic point of view. The undertaken study by article's authors in 2014, concerning geological documents and deposits maps, proves that in mining areas of collieries in Coal Company Ltd. in 116 residual parcels there is 219 978 685 Mg of energetic coal, while in 67 parcels in Jastrzębska Coal Company Ltd. there is 16 774 014 Mg of coking coal. The requirement of rational deposit exploitation in a colliery implicates considerations in the range of the possibilities of coal exploitation in residual deposits. These considerations are undertaken especially in collieries in which there is the lack of operational coal deposits.

Making the decision of residual deposits eksploitation needs to be determined by the positive evaluation of its technical possibilities and potential economic effects, and the risk of a failure. The results of an assessment are of significant importance. Residual deposits exploitation, even though is technically possible, should not be realised if it is economically ineffective or is too highly risky to make losses or not to get back invested capital. In the article, the authors presented the method of validity evaluation of residual seam exploitation involving technical conditions of exploitation in collieries in the Upper Silesian Coal Basin, and economic aspects of making decisions in this area. The essence of the method is the elaboration of possible residual parcels exploitation variants in a colliery, and thereafter indicating the optimal variant due to economic effectiveness and risk criteria, taking into account technical constraints. In the article, the case study of making use of the elaborated method in one of the Upper Silesian Coal Basin collieries was given.

2. The characteristics of the method

The elaborated method of validity evaluation of residual hard coal deposits exploitation consists of five stages, which are interconnected.

1. Stage – Evaluation of technical possibilities of residual deposits exploitation

Technical possibilities of residual deposits exploitation should be evaluated on the base on the information concerning geoengineering parameters i.e. coal deposit thickness, the occurrence of natural hazards (rockburst, methane, water, gas and rock outburst), and the necessity of surface protection. Taking into consideration technical conditions of residual deposits exploitation in the Upper Silesian Coal Basin (Wodarski, 2014), it was assumed that residual deposits should not be exploitated which are classified as II and III degree of rockburst hazard, IV degree of methane hazard, II and III degree of water hazard, I, II i III degree of gas and rock outburst hazard, or are located under important surface objects, sensitive to the impact of mining exploitation (e.g. a motorway). It was also assumed as unjustified exploitation of residual deposits of a bed thickness less than 1,5 m. The above-mentioned conditions are technical constraints of residual deposits exploitation.

2. Stage – Elaboration of residual deposits exploitation variants

The posssibities of creating variants derive from, among others, coal seam exploitation systems. There are many examples of the application of different systems to exploit of residual deposits of hard coal (among others Mol & Kolasa, 2000; Mielniczuk et al., 2000; Chmiel et al., 2006; Juzek & Rojek, 2007; Zorychta et al., 2008; Turek & Lubosik, 2008b; Dubiński, 2013). Based on presented experience, it was stated that in condition of the Upper Silesian Coal Basin, the best systems for residual deposits exploitation are as follows:

– heading system and its variations: with necks, and with stone backfilling,
– shortwall and open end system,
– longwall: with the rotation of a mechanized longwall front, with a changing front length, with a pocket, with short complexes,
– longwall and open end system,
– shortfront system: open end with Continuous Miner,
– chamber and pillar system.

The decision concerning an exploitation system is determined significantly by colliery's preferences, deriving from e.g. staff's experience, technical equipment which could be applied to exploit parcels, or the possibilities of its financing. However, a decisive significance for a choice of an exploitation system have parcel's geoengineering parameters, such as, among others, the thickness and the slope of a coal bed, natural hazards (rockburst, methane, water, gas and rock outburst), and roof and floor conditions (Wodarski, 2014).

Except different exploitation systems, assumptive variants can differentiate from each other due to proposed technical equipment (e.g. the type of a cutting machine or roof support), the way of financing technical equipment (e.g. own capital or leasing, Bąk, 2008), or the number of simultaneuosly exploitated longwalls.

3. Stage – Preliminary selections of residual deposits exploitation variants

The basis for a preliminary selection of variants is the result of their economic effectiveness. To make this assesstment a deterministic approach, it is based on the analysis of net cash flow (Płaneta et al., 2000; Saługa, 2009; Kudełko et al., 2014). Net cash flow is the balance between cash inflows and outflows concerning residual deposits exploitation in a specific calculative period of time. The period is a time horizon, which should be assumed for an economic effectiveness assessment based on parcel exploitation time according to individual variants. It was assumed that the unit of a calculating period is one month. Net cash flow in individual units of a calculative period is calculated by a following formula:

$$NCF = Q_t \cdot C_j - K_{op} - P + A - N + K_r - SpK_r \qquad (1)$$

where:

NCF – net cash flow concerning residual parcel exploitation, PLN/month,
Q_t – the coal output from a residual parcel, Mg/month,
C_j – coal price, PLN/Mg,
K_{op} – operational costs, PLN/month,
P – income tax, PLN/month,
A – amortization, PLN/month,
N – capital expenditure, PLN/month,
K_r – credit, PLN/month,
SpK_r – credit payment (capital installments), PLN/month.

Coal output from a residual parcel is calculated by a formula:

$$Q_t = \rho \cdot \eta \cdot \sum_{i=1}^{n} h_i \cdot p_i \tag{2}$$

where:

- Q_t – coal output from a residual parcel, Mg/month,
- ρ – the specific gravity of coal, Mg/m^3,
- η – the coefficient of coal processing losses,
- n – the number of exploitated longwalls in a residual parcel, $i = 1, 2, ... n$,
- h_i – the sectional area of a coal seam, in the "i-th" exploitated longwall, m^2,
- p_i – the rate of advance of the „i-th" exploitated longwall, m/month.

Operational costs of a residual parcel is calculated by a formula:

$$K_{op} = k_{wyn} + k_{mat} + k_{rem} + k_{poz} + k_{pp} + k_{pt} \tag{3}$$

where:

- K_{op} – operational costs connected with residual parcel exploitation, PLN/month,
- k_{wyn} – the cost of salaries with charges, PLN/month,
- k_{mat} – the cost of reconstruction and other equipment, materials, etc, PLN/month,
- k_{rem} – the cost of equipment revovation, PLN/month,
- k_{poz} – other costs: depreciation of fixed assets, credit interests, leasing, PLN/month,
- k_{pp} – the cost of auxiliary process: ventilation, horizontal and vertical transport, backfilling, mechanical processing, PLN/month,
- k_{pt} – the cost of associated processes: environmental protection, waste disposal, PLN/month.

Depreciation of fixed assets is calculated by a formula:

$$A = \sum_{i=1}^{p} W_{si} \cdot S_{ai} \tag{4}$$

where:

- A – depreciation of fixed assets purchased for parcel explotation, PLN/month,
- p – the number of fixed assets which are depreciable, $i = 1, 2, ..., p$,
- W_{si} – the value of „i-th" fixed asset, which is depreciable, PLN/month,
- S_{ai} – the rate of „i-th" fixed asset, which is depreciable.

Capital expenditure connected with residual parcel exploitation, involving initial capital expenditure (e.g. for parcel opening cut and for purchasing machinery and devices), and operational expenditure (e.g. for re-enactment used machinery and devices) is calculated by a formula:

$$N = \sum_{i=1}^{p} N_{wi} + \sum_{i=1}^{j} N_{pi} + \sum_{i=1}^{p} N_{zi} \tag{5}$$

where:

- N – capital expenditure connected with residual parcel exploitation, PLN

N_w – expenditure on the implementation of new or the modernization of the existing developing headings, including the purchase and installation of machines and equipment, which are the first equipment of the headings, PLN,
p – the number of sharing excavation for exploitation of residual deposits, $i = 1, ..., p$,
N_p – expenditure on the implementation of new or modernization of the existing lines of ventilation, drainage, evacuation (fire) road, connection, transport, methane drainage, compressed air, wiring, prop pant and others, including the purchase and installation of machines and equipment, which are the first equipment of this line, PLN,
j – number of made or modernized lines or equipment, $i = 1, ..., j$,
N_z – expenditure on purchase of machines, equipment and fittings, PLN,
i – the number of purchased machines, equipment and fittings, $i = 1, ..., p$.

The calculated values of net cach flow in individual units of a calculative period enable the assessment of economic effectiveness of residual parcel exploitation variants base on the criterion of Net Present Value, *NPV*. The *NPV* is calculated as the sum of discounted cash flow:

$$NPV = \sum_{t=1}^{n} NCF_t \cdot a_t \tag{6}$$

where:
NPV – Net Present Value, PLN,
a_t – the discount coefficient, expressing the change of money value within time, calculated for a discount rate deriving from weighted average cost of capital (Kudełko et al., 2014),
other symbols as above-mentioned.

In the method, it is assumed that an analysed variant of residual parcel exploitation is economically effective when $NPV > 0$. Variants, which do not fulfil this condition, have to be rejected.

The basic problem assiociated with a deterministic approach in an economic effectiveness assessment using the analysis of net cash flow and a *NPV* criterion is the necessity of the certainty of input data. Meeting this requirement is rarely possible because hard coal exploitation is associated by the uncertainty of its conditions and effects. And despite the fact, that along with the progress of deposit development the uncertainty decreases, the complete knowledge of a coal bed is actually achieved after full exploitation of coal resources (Saługa, 2009). Taking it into account, the assessment of economic effects of residual parcel exploitation needs to include the uncertainty of input data. The possiblility of quantifying of the uncertainty in the form of probability distribution could be done by the measurement and the assessment of economic effects and the risk of not achieving them.

4. Stage – Assessment of economic effectiveness of residual deposits exploitation variants with a risk analysis

It is assumed that the risk of residual deposits exploitation is given as the probability of the situation when real economic effects are worse than previously determined (Jonek-Kowalska, 2014). And that is why, in the assessment of economic effectiveness of residual deposits exploitation variants taking into account the risk, a probabilistic approach is based on a Monte Carlo simulation. The simulation is based on an assumption that the best way to assess the risk is the analysis of a great number of scenarios which are possible in the future (Wodarski, 2009; Saługa, 2009). The basis of a Monte Carlo simulation is the determination of uncertain input parameters (connected with possible unfavourable event), which significantly affect the economic effectiveness of variants, using a *NPV* indicator. Furthermore, probability distributions and functions of uncertain parameters (random variables) are determined, and then – based on conducted simulations – their values and the corresponding result of *NPV*. The measurement of economic effectiveness of residual parcel exploitation is its expected value calculated due to a formula:

$$\mu_{NPV} = \frac{\sum_{i=1}^{n} NPV_i}{n} \tag{7}$$

where:
μNPV – expected value of *NPV*, PLN,
NPV_i – *i*-th simulation result, PLN,
n – the number of simulations.

Yet the measurement of risk is the standard deviation of *NPV*, calculated by a formula:

$$\sigma_{NPV} = \sqrt{\frac{\sum_{i=1}^{n} (NPV_i - \mu_{NPV})^2}{n-1}} \tag{8}$$

where: σNPV – standard deviation of *NPV*, PLN
other symbols as above-mentioned.

5. Stage – The choice of the optimal exploitation variant and the decision of its realisation

The obtained results: μ_{NPV} i σ_{NPV} allow to choose the variant of residual parcel exploitation which is optimal due to economic effectiveness and risk criteria, taking into consideration existing technical constraints. For this purpose the coefficient of variation should be calculated due to a formula:

$$CV_{NPV} = \frac{\sigma_{NPV}}{\mu_{NPV}} \tag{9}$$

symbols as above-mentioned.

The coefficient CV_{NPV} can be of negative or positive values. The negative value of CV_{NPV} shows high probability of making losses (above 0,5) as a result of residual parcel exploitation. This is why it was assumed that variants characterised by a negative value of CV_{NPV} should be rejected. The authors claim that in the present situation on a hard coal market, it is justified to consider the exploitation exlusively of variants characterised by a positive value of CV_{NPV} in the range from 0,00 to 0,78. Among these variants, the optimal variant should be chosen which is characterised by the minimal value of CV_{NPV}.

The value of CV_{NPV} of the optimal variant is a criterion of a rational decision of residual parcel exploitation. To achieve this purpose decision standards were proposed, given in the Table 1.

These standards are subjective, because the same values CV_{NPV} for different decision-makers are opportunities or threats and may result in a positive or a negative decision of residual parcel exploitation. Therefore, decision standards should be fixed individually for a colliery, in which residual parcel exploitation is considered.

TABLE 1

Decision standards and proposed responses to risk, depending on CV_{NPV}

CV_{NPV}	Risk assessment and decision standard	Reaction to risk
0,00÷0,33	*Low risk – acceptable.* The positive decision about residual deposit exploitation due to an estimated variant.	*Risk acceptance* – the consent to bear the effects of negative effects of a decision.
0,34÷0,78	*Important risk* *– possible to acceptance.* The positive decision about residual deposit exploitation due to an estimated variant is possible but after appropriate actions against risk	*Risk division* – the distribution of risk between partners; *Risk protection* – the creation of reserves, insurance against adverse events; *Risk reduction* – the implementation of actions which reduce adverse events;
0,79÷∞	*High risk* *– impossible to acceptance.* The negative decision about residual deposit exploitation due to an estimated variant.	*Risk wait out* – awaiting the change of conditions (e.g. market, geological-mining); *Risk avoidance* – no agreement to the consequences of adverse events.

3. The assessment example of residual deposit exploitation validity

In 2015, it was considered to decide of residual exploitation of „R1" parcel of 1 598 208 Mg resources of energetic coal, located in the bed 330 in one of collieries in the Upper Silesian Coal Basin. For validity assessment of this parcel exploitation, it was proceeded due to the five stages of the method.

1. Stage – Based on the information of geoengineering parameters of R1, presented in Table 2, technical possibilities of its exploitation were positively assessed.

TABLE 2

Geoengineering parameters of the residual seam part R1

Geoengineering parametrs		R1
Coal seam thickness		1,91m
The slope of a bed	transverse, longitudinal	5°, 9°
Hazdard	rockburst	—
	methane	I degree
	water	—
	gas and rock outburst	—
Conditions	roof, floor	concise roofs, durable roofs
The necessity of surface protection		—

2. Stage – Taking into consideration geoengineering parameters, it was assumed that the R1 parcel should be exploited with a heading system. One of decisive factors for choosing this exploitation system were colliery's preferences, and especially high level of experience of colliery's underground workers in applying this exploitation system.

For elaborating variants of R1 parcel exploitation with a heading system, it was pointed out the possibility of using four different types of roof support: ŁP7/V21/A, ŁP9/V21/A, ŁPrP/5/A/12 or ŁPSp/V32/4/5,8×3,1. Four variants of R1 exploitation, different due to the type of support, were oriented to analyse them in the aspect of the maximal making use of deposit. Furthermore, due to an average thickness of a bed (1,91 m), it was stated that the deposit would be exploited with roof ripping.

Additionally, it was stated to study the analysis of the influence of the number of headings on R1 parcel exploitation economic effectiveness. For this purpose, it was assumed that R1 parcel exploitation could be exploited with one or two headings.

To sum up, there were eight variants of R1 parcel exploitation, taking into account different types of support and a different number of simultaneously driven headings, presented in the Table 3. It was assumed that in all variants the bed 330 would be exploited with a heading machine Alpine AM-50, financed in the form of leasing (it derived from colliery's financial possibilities). Furthermore, it was assumed that coal haulage is light push-plate conveyors (by a heading machine), belt conveyors and push-plate conveyors. Ventilation is realised using a ventube ventilator. Additionally, any extra machinery and devices necessary for R1 parcel exploitation were at the disposal of a colliery, and it results in no additional financial expenses.

For the designing of R1 parcel exploitation, it was firstly assumed the way of its preparation, in the aspect of ventilation and the access to a mining field. Totally, 2 449 m of preparatory workings were planned to drive. Then, for chosen variants, exploitation projects were elaborated, which were characterised by specific technical and economic parameters, presented in the Table 4. For each variant, the width of a protective pillar was calculated (Białek, 1996).

It was assumed that R1 exploitation due to individual variants would be realised with a different number of exploitation headings, and it would result in different energetic coal resourses as follows:

- in variants I, II: 87 headings of total length – 33 979 m and resources – 469 186 Mg,
- in variants III, IV: 78 headings of total length – 30 369 m and resources – 538 212 Mg,
- in variants V, VI: 88 headings of total length – 34 396 m and resources – 446 189 Mg,
- in variants VII, VIII: 73 headings of total length – 28 734 m and resources – 477 730 Mg.

3. Stage – Based on the information about technical and economic parameters of R1 parcel, net cash flow was calculated in all units of a calculation period (the period of R1 exploitation lasted a few months more or less depending on a variant). It enabled to calculate NPV (Table 4), taking into account a 3% discount rate deriving from the cost of capital financing residual parcel exploitation. The results of the calculations show that $NPV > 0$ in variants I, II, III, IV, VII and VIII, and it means these variants are economically effective. However, variants V i VI are ineffective and should be rejected.

4. Stage – To make Monte Carlo simulations, it was assumed that the most important uncertain input parameters, affecting economic effectiveness of analysed variants, were coal price, the level of coal sale, the advance of exploitation headings, and operational costs. Based on 9 expert opinions (workers of Production Preparation Unit and scientific staff), probability distributions

TABLE 3

Assumptions concerning the accepted scenarios of seam part R1 exploitation

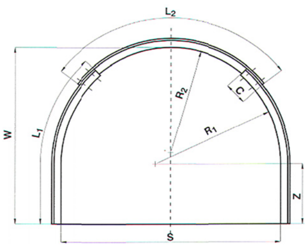
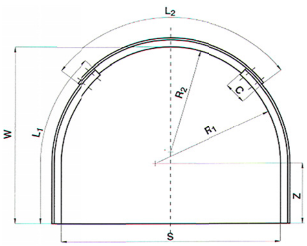
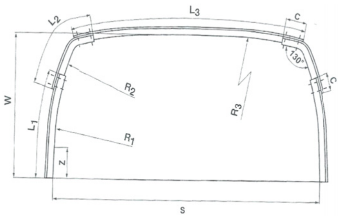
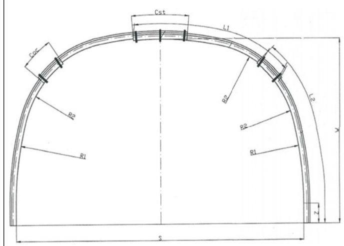
The characteristcs of a variant	**The number of a variant**							
	I	**II**	**III**	**IV**	**V**	**VI**	**VII**	**VIII**
Support	Liable steel arching **ŁP7/V21/A**, three-piece set  Dimensions: s = 4 300 mm, w = 3 100 mm; Set spacing (depending on strength parameters of rock mass) up to 1,0 m		Liable steel arching **ŁP9/V21/A**, three-piece set  Dimensions: s = 5 000 mm, w = 3 500 mm; Set spacing (depending on strength parameters of rock mass) up to 1,0 m		Liable steel arching **ŁPrP/5/A/12**, five-piece set  Dimensions: s = 4 200 mm, w = 3 000 mm; Set spacing (depending on strength parameters of rock mass) up to 1,0 m		Liable steel arching **ŁPSp-V32/4/5.8x3.1,** four-piece set  Dimensions: s = 5 800 mm, w = 3 100 mm; Set spacing (depending on strength parameters of rock mass) up to 1,0 m	
The number of exploited headings	1	2	1	2	1	2	1	2
Exploitation system	Heading system							
Cutting machine	Heading machine Alpine AM-50							
Coal haulage	Light push-plate conveyors (by a heading machine), belt conveyors and push-plate conveyors							
Other equipment	Ventube ventilator, electrical equipment							

TABLE 4

Basic technical and economic parameters and evaluation results of variants of seam part R1 exploitation

Parameters and assessment results of the exploitation of R1 parcel	Unit	The number of a variant							
		I	II	III	IV	V	VI	VII	VIII
Cross-sectional area of a heading	m^2	11,1	11,1	14,8	14,8	11,9	11,9	15,4	15,4
Cross-sectional area of a bed in a heading	m^2	9,2	9,2	11,7	11,7	8,7	8,7	10,9	10,9
Width of a protective pillar	m	10,0	10,0	11,0	11,0	10,0	10,0	11,0	11,0
Advance of a heading	m/month	435	870	435	870	435	870	435	870
Number of headings		1	2	1	2	1	2	1	2
Specific gravity of coal	Mg/ m^3	1,4	1,4	1,4	1,4	1,4	1,4	1,4	1,4
Coal output	Mg/month	6 039,0	12 078,0	7 134	14 268	5 271	10 542	6 663	13 325
Coal price	PLN/Mg	231,0	231,0	231,0	231,0	231,0	231,0	231,0	231,0
Calculation period	months	84	42	75	38	84	42	72	36
Cost of salaries with charges	PLN/month	404 250,0	707 437,5	404 250,0	707 437,5	404 250,0	707 437,5	404 250,0	707 437,5
Cost of support	PLN/month	544 053,0	1 088 106,0	644 404,8	1 288 809,6	544 082,5	1 088 164,9	743 985,0	1 487 970,1
Cost of electrical equipment	PLN/month	95 160, 0	190 320,0	95 160, 0	190 320,0	95 160, 0	190 320,0	95 160, 0	190 320,0
Leasing cost of a heading machine	PLN/month	90 750,0	181 500,0	90 750,0	181 500,0	90 750,0	181 500,0	90 750,0	181 500,0
Cost of vertical transport of a crew	PLN/month	5 551,0	9 714,2	5 551,0	9 714,2	5 551,0	9 714,2	5 551,0	9 714,2
Cost of coal transport in a shaft	PLN/month	3 163,3	6 368,0	4 223,5	8 492,0	3 462,1	6 957,1	4 393,5	8 836,2
Cost of material transport	PLN/month	15 766,7	31 533,3	15 766,7	31 533,3	15 766,7	31 533,33	15 766,7	31 533,3
Haulage cost	PLN/month	19 324,8	38 835,2	25 752,8	51 780,3	21 110,4	42 421,3	26 789,4	53 879,5
Ventilation cost	PLN/month	18 019,5	36 039,1	24 026,0	48 052,1	19 683,5	39 367,0	25 000,1	50 000,1
Cost of mechanical processing	PLN/month	50 244,4	100 971,5	66 957,3	134 628,7	54 887,0	110 295,5	69 652,4	140 086,6
Cost of waste disposal	PLN/month	18 299,2	34 147,0	27 703,7	50 940,6	26 500,3	51 010, 6	34 065,0	65 215,2
NPV	Thousands of PLN	1 939 873,4	5 187 880,6	13 230 692,3	16 685 127,5	**–4 692 123,4**	**-924 834,9**	1 318 746,5	4 096 890,6
μNPV	Thousands of PLN	–1 331 302,5	888 461,8	8 980 342,0	11 118 477,1	—	—	–3 260 407,8	–1 686 838,7
σNPV	Thousands of PLN	6 755 672,9	6 524 154,5	6 646 361,5	7 254 056,5	—	—	6 702 245,3	6 441 432,1
CV_{NPV}	—	**-5,07**	7,34	0,74	**0,65**	—	—	**–2,06**	**–3,82**
Risk assessment	—	High	High	Medium	**Medium**	High	High	High	High
Proposed decision	—	*Exploitation abandonment the rejection of a variant*	*Exploitation abandonment Risk wait out*	*Parcel exploitation, risk division*	***Parcel exploitation, risk division***	*Exploitation abandonment the rejection of a variant*	*Exploitation abandonment the rejection of a variant*	*Exploitation abandonment the rejection of a variant*	*Exploitation abandonment the rejection of a variant*

and functions of analysed uncertain parameters were determined. Furthermore, based on results of 200 simulations, random variables and as a result NPV were calculated. Simulation results allowed to determine the cumulative probability function of NPV, and to calculate μ_{NPV} i σ_{NPV} (presented in Table 4).

5. Stage – Based on undertaken calculations of CV_{NPV} (Table 5), it was stated that variants I, VII and VIII are characterised by a negative value of this coefficient. It means the rejection of parcel exploitation in these variants because of too high risk of financial losses. The analysis of results of CV_{NPV} in other variant allows to state that the optimal variant of R1 parcel exploitation is IV variant. It is the highest expected economic effects and acceptable risk of not achieving the results (p = 0,07).

Based on assumptive decision standards (Table 2), the authors stated that a positive decision on R1 parcel explotation is posssible according to the assumptions of IV variant. In case of negative events in the future (among others an unfavourable economic situation), it was proposed to divide risk effects between a colliery and an external firm providing service of mining works.

4. Conclusions

Hard coal residual parcels exploitation can bring in many benifits. The most important benefits are the limitation of losses of coal resources, the reduction of stress concentration zones in rock mass, and the improvement of keeping up workings. The significance of residual parcels for a colliery with the lack of coal resources should be emphasized. In these collieries the possibility of residual deposits exploitation is one of key aspects of extension of colliery's durability.

At present, making a decision of hard coal exploitation from residual parcels cannot be based only on above-mentioned benifits and the assessment of present technical possibilities of exploitation. Today, the essence of colliery's functioning on a competitive market is economic effectiveness of its operational actions (Dubiński i Turek, 2014) which determines the decision-making process of residual deposits exploitation.

The proposed, in the article, method enables the assessment of the economic effectiveness of residual parcels exploitation. In the method, the present situation on a coal market was involved, and especially market's variability and predicted possible negative events in the future, e.g. unfavourable economic situation, and as a result decreasing coal price and coal demand. It was assumed that the criterion of a positive decision of exploitation is the risk assessment of making losses and not getting back the invested capital. The assessment needs to analyse (making use of Monte Carlo simulations) a great number of scenarios which are possible in the future.

The elaborated method has two fundamental advantages. Firstly, appropriate assumed assessment critera enable to choose the optimal variant of residual parcel exploitation, due to economic effectiveness and risk criteria, taking into account technical constraints. Secondly, the method involves decision standards which support the analysis in the range of residual parcel exploitation. In these standards, decisions and corresponding risk reactions are given. Despite the fact that these standards are subjective, they could be treated as a benchmark and changed – appropriately to colliery's future situation, when residual parcel exploitation is planned.

The proposed method was applied in a variant analysis of residual parcel exploitation. The results of its application in one of collieries in the Upper Silesia Coal Basin were crucial to make a decision of residual parcel exploitation and actions against risk.

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