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Impact Assessment of Run-of-Mine Dilution on Hard Coal Production Efficiency

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Abstract
An impact assessment of the run-of-mine dilution on hard coal production efficiency is presented in the article. The data were taken from three longwall faces, conducted in a thin seam. Empirical data were subject to a statistical analysis aiming at the development of a mathematical model of an advance of longwalls depending on a quality structure and an amount of the run-of-mine from the plough-equipped longwall faces. The Monte Carlo method, an analysis of agglomerations and an analysis of scenarios enabled to develop a mathematical model. Afterwards, an analysis of the economic efficiency of the mining process, bearing in mind scenarios assuming an improvement of the run-of-mine quality, was conducted.

Keywords
run-of-mine, dilution, efficiency, hard coal

Introduction

Poland still belongs to a relatively small group of European countries, where a generation of electric energy and heat is based on solid fossil fuels: hard coal and lignite. About 77% of electric energy was produced from coal in 2019 (47.8% - from hard coal and 29.0% from lignite). According to the present economic policy, coal plays and will play a crucial role in several years to come as regards energy security and independence. During the after-the-war period, twenty-two big hard coal mines and five open cast mines were constructed. A continuous increase of hard coal annual production rates could be observed over the period of 33 years until 1979, when the highest annual production rate was reached, i.e. 201 mils. Mg. At the beginning of the sixties, a modernisation of mines started consisting in, among others, a merger of small mines. Within a period of the following twenty years, more than twenty small mines were combined, so in 1980 the total number of hard coal mines was 66 (instead of 81). Political and economic, as well as social changes which started in 1989, forced the decision-makers to adopt the mining sector to the requirements of the market-oriented economy. The last thirty years were not good for the mining sector in general. One of the mines, which took advantage of new economic conditions and changed its functional strategy, was the Bogdanka Mine, situated in the Lublin Coal Basin. The first longwall face started its operation in 1986. It was a test longwall face. In 1986 the second longwall face in the Bogdanka Panel was started, and the first longwall face in the Nadrybie Panel began its production in 1987. However, the production breakthrough took place in November 1988. Within the years 1988-92, the number of longwall faces increased to five. The period of recent forty years enabled a new approach to the development and exploitation of deposits situated in difficult mining-and-geological conditions at great depths. It included a restructuring process oriented toward increasing work safety and productivity as well as decreasing operational costs (top productivity, top production concentration and lowest costs). A drastic drop in coal prices over the years 2014-2019 and difficulties with selling coal made the Bogdanka Mine decision-makers elaborate a new production strategy based on controlling the production in the scope of commercial coal, on stabilising production parameters and on improving the quality of the run-of-mine, i.e. on reducing a dilution of the run-of-mine. The problems indicated above were a prerequisite for undertaking research work on an impact assessment of run-of-mine dilution on hard coal production efficiency in the LW Bogdanka. Using information and monitoring technologies, an innovative production management system was successfully implemented. It should be borne in mind that a phenomenon of mineral dilution results from the mechanisation of mining processes. (Wright, 1983; Ingler, 1984; and Knissel et al., 1955) analysed the phenomenon of deposits impoverishment. (However and Noppe, 2003) suggested a classification of impoverishment into three groups:

- primary impoverishment – floor coal-cutting with a roof and floor layers using a shearer or a roadheader,
- secondary impoverishment – cutting uplifted floor or collecting rock after the roof fall,
- third-rate impoverishment – coal impurities generated at cleaning powered-roof supports or mixing dirt generated at driving stone roadways with the coal run-of-mine from longwalls.

According to Saedi et al., 2008 in underground mines, off-seam dilution (OSD) varies from 15% to 30% in relation to mining and geological conditions as well as to technical parameters of the mining system. The first publications on dilutions appeared in 1971 (Popov, 1971), but since 1973 Agoshkov described relationships among parameters of minerals and dilutions (Agoshkov, 1974; Agoshkov and Panifilov, 1973; and Ahoshkov and Rysov, 1967). Some tests were conducted in the Stillwater Mine in Montana by (Annels, 1996). He stated that impoverishment increases when the seam thickness decreases. The subject matter of dilution in the case of metal ores was investigated by Soviet researchers and scientists such as (Bajkov, 1973 and 1978; Bajkov and Kuchko, 1974; Kaplunov, 1938 and 1948; Mielnikov, 1973 and 1974). The results of their research work were used to develop similar methods in the hard coal mining industry.

Research objectives

Several research methods, techniques and tools were used for an impact assessment of the run-of-mine dilution on a hard coal production efficiency.

They included as follows:

- expert analysis of Polish and foreign literature,
- mathematical modelling,
- probabilistic modelling,
- an assessment of economic efficiency,
- a statistical analysis,
- a simulation with the use of the Monte Carlo method,
- an analysis of agglomerations,
- an analysis of scenarios.

The research methods presented above were used to confirm that it is possible to achieve positive economic results due to a rationalisation of coal winning processes. An impact assessment of the run-of-mine dilution on hard coal production efficiency was based on the data collected from three longwall faces conducted in a thin seam at the LW Bogdanka.

Impact assessment of deposit impoverishment on the economic efficiency of a coal production process in an underground mine

Resource and economic assessment under uncertainty and risk is difficult and complex. Many geological, mining, technical and economic aspects should be taken into consideration. It should be borne in mind that the assessment process itself is subject to errors in the scope of measurement and interpretations of the obtained data as well as errors resulting from lack of detailed knowledge. Uncertainty about the real value of geological parameters plays a significant role. In many cases, the information available is insufficient and can cause an incorrect interpretation, especially at the initial stages of the mine development (Kopacz et al., 2019).

Efficient mining operations require control of key geological and mining variables relating to the deposit (Biały, 2014; 2015; 2016; 2017), to coal deposition conditions in seams and the applied mining technology. Relationships among different mining and geological conditions as well as their impact on a model of a mine, mining technology, costs of processes, quality of commercial products and economic efficiency of mines were investigated by (Karbownik, 1987; Lisowski, 2001; Magda et al., 2002; Lorenz et al., 2002; Przybyła and Chmiela, 2007; Rajwa, 2007; Dyczko and Kopacz, 2008; Lubosik, 2009; Sobczyk, 2009; Brzychczy, 2012; Wodarski and Bijańska, 2014; Grudziński, 2012 and 2013; Turek, 2013; Kopacz, 2015). These publications confirm the fact that a generation of a smaller amount of dirt in underground workings contributes to an improvement of coal production economic efficiency.

A thirty-year activity of the Bogdanka Mine is based on longwall exploitation with the use of shearers (Figure 1), which ensure a successful operation in seams above 1.6 m. In this mine, the production rates reached 15000Mg/day in the case of mining seams of the height from 1.6 to 2.0 m and up to 20000 Mg/day in the case of mining seams of the height from 2.0 to 2.5 m.

Fig. 1. Longwall system with the use of a shearer at the Bogdanka Mine

In the case of seams below 1.6 m in the longwalls equipped with shearers, cutting the roof and floor layers is necessary to ensure the right longwall height for an operation of a longwall system. Such an operation causes a bigger loading of a shearer, a dilution of coal with rocks from the layers adjacent to the seam and a deterioration of the run-of-mine quality.

In 2010 a plough system (Figure 2) was implemented in the Bogdanka Mine to improve the mining efficiency of longwalls of 1.6 m height. An implementation of ploughs improved the quality of the run-of-mine due to a reduction of cut rocks coming from the roof and floor rock layers.

Fig. 2. Plough system applied in the Bogdanka Mine

According to the experience gained in American mines, a 1% reduction of dirt in the run-of-mine caused a two-digit improvement of the production profitability.

The longwall 7/V/385 equipped with a shearer enabled to obtain 68% of coal in the run-of-mine, and in the longwall 1/VI/385, even a better result was achieved, i.e. 75% of coal in the run-of-mine. Until 2019 the Bogdanka Mine purchased four plough systems in total. The first one, applied in seam No. 385/2 of the thickness 1.55 m, enabled to reach the daily production rate on the level of 10000 Mg. The average daily gross production rate was 8200 Mg, and the total production rate over the period: April-October was 1382 thousand Mg at the average daily longwall advance of 10.0 m, the average monthly advance of 247.4 m and the average daily plough operation time reaching 5h 23 min.

The Bogdanka Mine reached the world record as regards the daily production rate from low seams, which was 22400 Mg. However, this record was broken by the miners from the Pinnacle Mine (USA) in August 2019. The daily production rate in the longwall face of the height 1.42 m and length 294 m reached 29420 Mg using the Cat Gleit hobel GH1600 automatic plough system. Soon after, Bogdanka increased its daily production, which in October 2019 reached 33612 Mg.

The seam No. 385/2, at a depth of 950 m, is one of the richest and most regular hard coal seams in the Lublin Coal Basin.

Another example of implementing the plough technology concerned the longwall 7/VII/385 of the 305 m in length and of the panel length 5 km in the seam of the thickness 1.25-1.60 m, which was equipped with a plough system which was previously used in the longwall 1/VI/385.

In 2014 the Bogdanka Mine purchased the following two plough systems. At present, four plough systems are sufficient for keeping the production rates on the required level for several years to come. Both cutting technologies: shearer systems and plough systems, will be used in the case of four longwalls to be exploited, with six mechanisation systems at the disposal, i.e. three plow systems and three shearer systems or four plough and two shearer systems.

The next step of the research work included the development of a correlation matrix for variables determining shearer-equipped longwall faces and a correlation matrix for variables determining plough-equipped longwall faces. From the statistical point of view, correlation analysis in the case of shearer-equipped longwall faces showed essential relationships among:

- the time of longwall face operation, total production rates of coal run-of-mine and total operational costs,
- the seam thickness and net daily production rates,
- the amount of floor and roof rippings and the amount of extracted coal,
- the gross daily advance and average net and gross daily production rates,
- the gross daily production rates and the seam thickness as well as the cutting height,
- the total production rates of the run-of-mine (and coal) from the longwall face together with the total operational costs, including direct costs such as: use of materials, energy, repairs, wages, as well as other costs.

As regards, plough-equipped longwalls high and essential values of correlation coefficients were obtained in the case of:

- an advance, net and gross production rates and operational costs,
- a seam thickness, roof fall, exploitation door, net and gross production rates and operational costs,
- a net amount of coal and seam height, roof fall and operational costs.

A conducted correlation analysis confirmed relationships among an advance of longwall faces, seam thickness, daily and total coal production rates and even to a bigger extent – of dirt as well as operational costs. It showed that in the case of shearer-equipped longwalls, there is a correlation relationship between an advance and operational costs. But in the case of plough-equipped longwalls, this relation is stronger, although a correlation is positive. Besides, there is a correlation relationship as regards an average gross daily production rate of the run-of-mine.

Impact assessment method of the run-of-mine dilution on the economic efficiency of coal production

An impact assessment of the run-of-mine dilution on the economic efficiency of coal production was conducted with regard to an operational life cycle of a longwall face which included development activities, a production phase, disassembly of equipment and liquidation of the face (Kustra and Sierpińska, 2013; Magda et al., 2002). Due to a specificity of the obtained data, the analyses were conducted on the basis of generalised data from the plough-equipped longwalls: 1/VIII/385, 6/VII/385 and 3/VI/385 generated for a big population of 10 thousand variables, covering a full operational life cycle of one longwall face.

The analysis includes several key stages:

- preparation of data,
- a generation of big random samples,
- construction of an economic efficiency model.

The thematic scope includes geological data (ash content, calorific value, humidity, weight of run-of-mine), cost data, data analysis and construction of an economic efficiency model, an analysis of agglomerations, verification of results and finally, a generation of assessment results in the form of scenarios. This approach combines qualitative features of the run-of-mine with the features of the mining system and exploitation costs.

A model of economic efficiency assessment is also based on the data from empirical samples and the samples generated using the Monte Carlo method and grouped into 11 clusters implemented in the RapidMiner Studio 5 Software.

Impact of run-of-mine dilution on production efficiency

The scope of the research work included the following tasks:

- A collection of geological data from the SYSKON system (ash content, calorific value, moisture content, weight of the run-of-mine).
- Preparation of technical data (advance, statistics of break-downs taken from the SIK system and their combination with the data from the SYSKON system).
- A specification of costs.
- An implication of historical operational data for a model.
- Data analysis.
- A selection of mixes and a generation of big random samples – a construction of a simulation model.
- Construction of an economic efficiency model – a generation of a discount model in the NPV method.

Analysing the steps presented above, it can be seen that quality parameters of the run-of-mine are combined with the features of the mining systems and the production costs.

An introduction of the Monte Carlo method improved the modelling quality and generated big data sets. Four different scenarios were defined: a basic scenario, an optimistic scenario, a pessimistic scenario and an optimised scenario. An impact assessment of the run-of-mine dilution (dirt) on the economic efficiency of a mining process was conducted based on the data from three plough longwall faces. The characteristics of these faces are given in Table 1.

Table 1. Characteristics of plough longwall faces under analysis [0].

Specification	3/VI/385	6/VII/385	1/VIII/385
Name of district	G-6	G-4	G-1
Name of system	Plough system No. 3	Plough system No. 2	Plough system No. 1
Plough	Bucyrus 3	Bucyrus 2	Bucyrus 1
Number of support	142 s x 1.75 m	172 s x 1.75 m	172 s x 1.75 m
Panel length	2300 m	4850 m	5024 m
Longwall length	250	303.8	303.8
Panel data analysis	410 m – 1500 m	2700 m – 4400 m	4531 m – 5024 m
Period data analysis	12.01.2015 –	13.10.2014 –	24.11.2014 –
Average seam height	1.45	1.42	1.31
Average roof fall	0.55	0.5	0.4
Average floor ripping	0.33	0.35	0.43

As the result of such an approach, a typical plough face was generated. A stochastic model was constructed, and it was used for generating big sets of representative data. In the following step, an analysis of aggregations was performed with the use of the RapidMiner Studio 5 software. According to the traditional formula, the net present value – NPV was a sum of present values (up-dated) of annual cash flows reduced by costs of initial investments. The equation, enabling to calculate NPV, is as follows:

$$NPV = \left[\sum_{t=1}^{n} \frac{CF_t}{(1+d)^t} \right] - I_0 \qquad (1)$$

where:

CF_t – cash flow in the t year [PLN],

I_0 – initial investments [PLN],
d – discount rate [%],
n – total number of periods required for a project realisation.

NPV is a very good tool to be used to assess economic efficiency. The bigger NPV, the bigger profits result from a project realisation. A block model was constructed on the base of analysed longwalls (Klačková et al., 2019). A stratigraphic model of the Bogdanka deposit was generated on the grounds of surface boreholes and underground test holes (Figure 3).

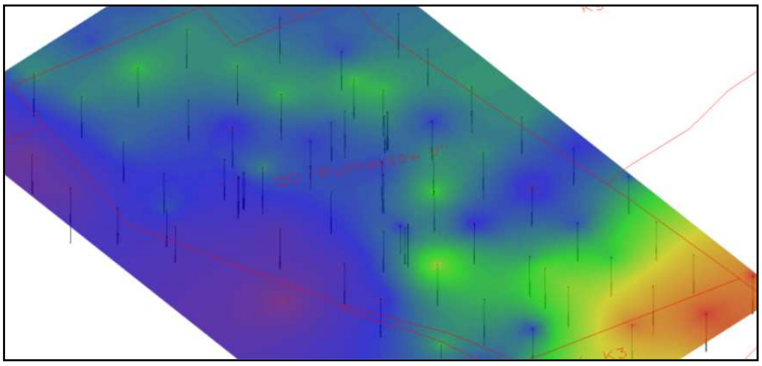

Fig. 3. Model of surface and location of test holes.

Such a stratigraphic model enabled to model a fall of roof rocks.
In the case of the plough longwall 1/VIII/385, a roof fall (in yellow) is clearly visible (Figure 4).

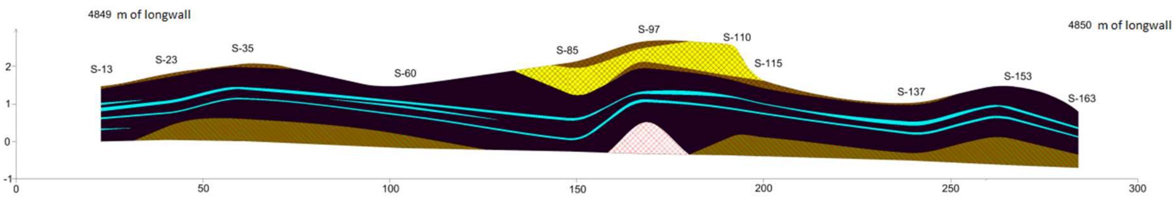

Fig. 4. Profile of 1/VIII/385 plough longwall on 30th November 2014 [0].

The forecast of roof rockfall was made with the use of the MineScape software developed by the ABB Company. Then a statistical assessment of empirical data, which included an expert analysis, was conducted. An analysis of regression, variance and correlation revealed some difficulties in selecting a statistical model. The Statistica software was used in this case.

The conclusions drawn from the statistical analysis enabled to state explicitly that there is a strong relationship between the longwall face advance and the run-of-mine weight. The quantitative criterion seems to dominate the qualitative criterion, which is confirmed by a decreasing calorific value of the run-of-mine (Kuric et al., 2019; Pivarčiová et. al., 2019). Conclusions drawn on the basis of analyses of agglomerations are more appropriate than those based on a linear model, which can be misleading in particular for a population composed of a few data sets within the whole life cycle. Such an approach enabled identifying sets of similar observations and determining descriptive statistics for them, i.e. technical and economic relationships. As already mentioned, a selection of theoretical distributions for empirical data was made with the use of the Crystal Ball software and the Monte Carlo method. Finally, the A-D (Anderson-Darling) method was chosen, which is sensitive to so-called thick tails. D – value statistics were high and sufficient for verification of selection correctness of the theoretical distribution of empirical data. To obtain a sufficiently big number of data for an analysis of agglomerations, big sets of observations (about 2500) were generated for the following variables: advance, the weight of the run-of-mine, calorific value, ash content, amount of dirt that can be eliminated. The Latin hypercube technology was used for sampling. A distribution of dirt, which could be eliminated, was based on an expert assessment of possibilities of leaving a determined amount of stone in the plough longwall according to geological guidelines. Finally, using the Monte Carlo method, it was possible to re-create a standard plough face model and generate big data sets (Wiecek et al., 2019). This step ended the assessment phase and the analytical material preparation, which enabled to start the phase of constructing assumptions of a mathematical model incorporated in the economic efficiency model. Analysed data, both from empirical samples as well as generated using the Monte Carlo method, were grouped into 11 clusters in the RapidMiner Studio 5 software.

A relationship between average ash content and an advance for a given cluster in the mathematical model is shown in Figure 5.

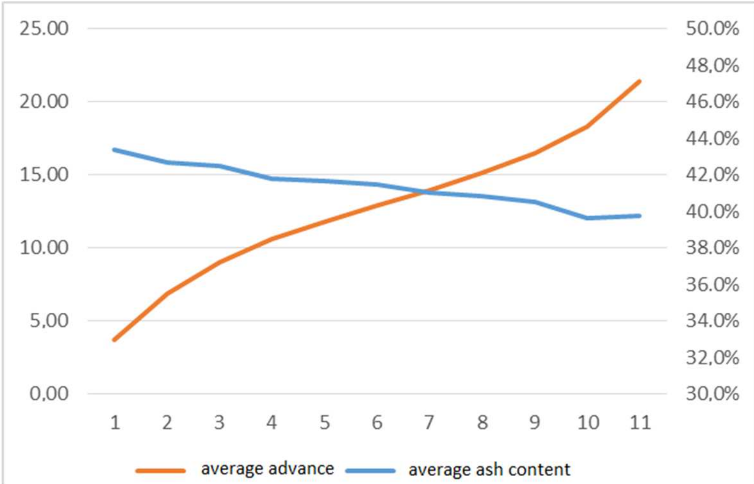

Fig. 5. Relationship between average ash content and an advance.

A reduction of dirt in a longwall face has an impact on reducing ash content. The formula used for calculations was based on the mass and energy conservation law:

$$m_p \times p_p = sk_{du} \times 100\% + (m_p - sk_{ds}) \times p_n \tag{2}$$

where:
m_p – total weight of the run-of-mine [Mg],
p_p – primary ash content according to indications of ash-meters [%],
sk_{ds} – weight of dirt which is possible to be eliminated [Mg],
p_n – new ash content in the changed run-of-mine structure [%].

After transformations, the formula for an assessment of new ash content is:

$$p_n = \frac{m_p \times p_p - sk_{du} \times 100\%}{m_p - sk_{du}} \; [\%] \tag{3}$$

The next stage of calculations was oriented onto a determination of an advance. The total effect of efficiency increase was calculated from the following formula:

$$E = \frac{\sum n_p}{\sum p_p} - 1 \; [\%] \tag{4}$$

where:
E – efficiency increase [%],
p_p – sample advance [m],
n_p – new sample advance [m].

In Figure 6, relationships in clusters among the run-of-mine weight and the advance, as well as the ash content, are shown.

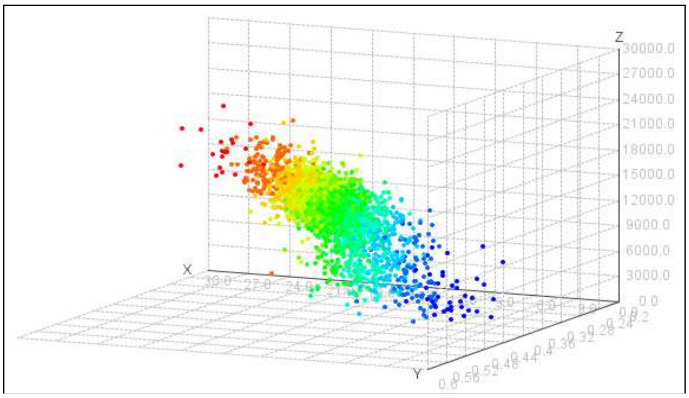

Fig. 6. Relationship in cluster among the run-of-mine weight [Mg] and the advance [m/d] and the ash content [%].

It is worth seeing in clusters a changeability of the ash content in relation to the advance, as it is shown in Figure 7.

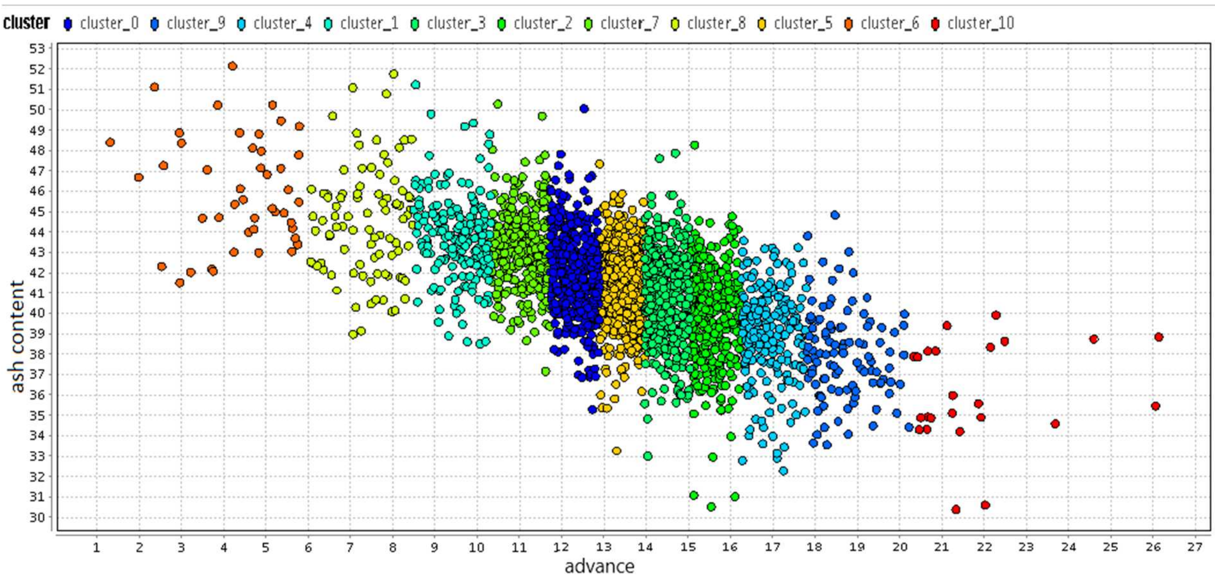

Fig. 7. Changeability in clusters of ash content in relation to the advance.

Basing on the conducted analysis of agglomerations, it was calculated that the maximal advance increase in relation to average values experienced at the LW Bogdanka is 8 metres per day. From the scientific point of view, it was interesting to investigate the impact of geological, mining, technical and organisational conditions on the longwall face advance (Kuric et al., 2021). An inquiry method was used. In total, 440 questionnaires were distributed, but 165 were analysed as the other ones were either incomplete or completed incorrectly. According to the questionnaire respondents the biggest impact on production rates in plough longwalls had geological conditions (51%) (Liaposhchenko et al., 2019). Technical and organisational conditions had an impact of 24% and 25%, respectively. As regards the production purity, 62% of respondents regarded geological factors to have the biggest impact, 22% of them chose technical factors and 16% - organisational ones.

Model of economic efficiency (profitability)

A rationalisation of a coal production process gives big savings as regards operational costs. It concerns, in particular, the content of dirt in the run-of-mine. The FCFF (free cash flow to firm) was used for a calculation of economic-and-financial results, taking into consideration:

- production of the run-of-mine and of coal,
- identified reductions of costs connected with mining a smaller amount of dirt,
- an income,
- operational costs of development work, of equipping longwall faces, of production from plow – equipped longwalls, of drawing off the faces.

Based on this information, a structure of the economic efficiency model was generated. It included as follows:

- Total net production rate from longwalls and road-headings.
- Income.
- Mining costs of using a plough technology.
- Amount of eliminated dirt.
- Total savings.
- Total costs.
- EBIT (income before tax, interests).
- Depreciation.
- Taxes.
- NOPAT (net operational profit).
- FCFF (free cash flow to firm).

An analysis of the economic efficiency enabled to present net values for different scenarios, which vary from 1496.0 to 1777.4 mil. PLN. However, total net profits are from 74.6 to 281.5 mil. PLN. Table 2 shows the results of the economic efficiency assessment.

Table 2. Results of economic efficiency assessment.

Type of scenario	Specification	NPV [million PLN]	Savings in relations to present state [million PLN]
"as is"	Present state	1 495.9	0.0
"to be"	Pessimistic scenario	1 570.5	74.6
"to be"	Basic scenario	1 580.6	84.7
"to be"	Optimistic scenario	1 753.5	257.6
"to be"	The scenario at full optimisation effects	1 777.4	281.5

In the result of conducted research investigations, it can be concluded that an exact driving of the plough head along the seam floor gives positive economic effects as it enables to avoid cutting a part of the seam containing small amounts of coal but big amounts of dirt, which causes an increase of ash content and thus reduces the quality of the feed directed to the preparation plant.

Analysing the production balance of wastes generated in the LW Bogdanka over the years 2005-2014 (Kopacz, 2015), it can be seen that the annual production waste varied from 2.169 to 5.624 mils. Mg. According to (Kopacz et al., 2019), over the years 2007-2013, contents of dirt in the gross weight of the run-of-mine in the Polish hard coal mines increased from 29.6% in 2007 to 31.5% in 2013. From the information published in (Dyczko, 2018), it can be seen that in the LW Bogdanka in 2013, the content of dirt in the gross run-of-mine was about 37.7%. The net coal index was 62.3%. The forecast of coal production rates for the years 2020-2034, presented in (Bajkov, 1973), assumes that an annual amount of dirt will stabilise on the level of about 5.1 mils. Mg, whereas the forecasted net coal content will be about 69.5%. The structure of production wastes in the LW Bogdanka over the years 2005-2014 (Kopacz, 2015) indicates that about 85% of production wastes came from the coal mechanical preparation process. It can be stated that processes of separating dirt from coal in the mechanical preparation plant significantly impact hard coal production efficiency (Figiel et al., 2020). In this context, research and development work concerning an improvement of quality and production rates of coal mechanical preparation processes (Kowol and Matusiak, 2019 and 2019) play an important role. During these processes, a relatively large amount of dust is generated (Lutyński, 2016). It is a hazard to occupational safety and health (Lutyński, 2017). Control of this hazard is the subject matter of numerous research projects such as, for example, (Bałaga, 2019).

A correct selection of the seam mining technique and technology, in the aspect of minimising the dirt content in the run-of-mine, apart from an essential impact on the hard coal production efficiency, also has a significant impact on occupational safety and health of miners. A cleaner seam extraction reduces free crystalline silica (FCS) in the dust generated in the process of cutting the rock mass. Coal dust in underground workings contains from 2% to 10% of free crystalline silica (Finkelman et al., 2002 and Önder et al., 2009). They belong to dust causing fibrosis, pathomechanisms of silicosis. The measurements taken at workplaces in the mining industry (Mikołajczyk et al., 2010) confirm the average concentration of this dust on the level of 2.31 mg/m^3. The maximal permissible concentration was exceeded in the case of 56.75% of measurements. The dust concentration can be effectively reduced by efficient ventilation and spraying installations (Prostański, 2017 and 2018).

Conclusions

An impact assessment of the run-of-mine dilution on hard coal production efficiency in the LW Bogdanka was started with the preparation of the data sample. These data were collected from three longwall faces. An assessment of empirical data was started with statistical analysis to select an optimal model, enabling to generate a mathematical model including an advance of longwalls, the quality structure and production rates of the run-of-mine from plough longwall faces. Qualitative and quantitative data were taken from the SysKon400 equipment installed on the conveyors.

The statistical analysis revealed small relationships among the ash content and other quality parameters of the run-of-mine in linear and non-linear models, so the Monte Carlo simulation and analysis of agglomerations were introduced. As the result of such an approach, a mathematical model of the plough longwall faces was constructed. The economic effect was estimated based on calculations of the amount of dirt eliminated due to no floor cutting as well as potential savings relating to costs of processes. These savings were identified using a cost structure in the LW Bogdanka.

As the assessment process turned out to be extremely complicated, an analysis of scenarios was introduced in the function of advance increase and an improvement of extraction purity. In general, the coal resources in thin seams are in the range of 66.8 mils. Mg the LW Bogdanka can achieve:

- Total cost reduction in the amount of 170 mils. PLN.
- Maximal total profit (NOPAT) in the amount of 384.1 mils. PLN.
- Values of income effects according to the NPV method in the amount of 281.5 mils. PLN.

The research project results presented in the article confirm that there are possibilities and measures of optimising the mining processes regarding the run-of-mine dilution impact on hard coal production efficiency in the LW Bogdanka.

References

Agoshkov M.J. Technical and Economic Assessment of Gaining Minerals from Rocks. Niedra Publishers, Moscow, 1974.

Agoshkov M.J.; Panifilov E.J. Individual Classification of Losses in Mining Deposits of Hard Minerals. Gornyj Zhurnal (Mining Journal) No. 3, 1973.

Agoshkov M.J.; Rysov P.A. Improvement of Methods of Calculating Losses and Impoverishment of Minerals in Mining Ore Deposits Using Roof Caving Systems. Gornyj Zhurnal (Mining Journal) No. 3, 1967.

Annels A.E. Assessment of Minerals Deposits – Practical Approach. 1st Edition. Chapman and Hall. UK, 1996.

Bajkov B.N. Determination of Losses and Impoverishment in Opencast Mining of Colour Metallurgy. Niedra Publishers, Moscow, 1978.

Bajkov B.N. Social-and-Economic Problems of Using Rocks. Niedra Publishers, Leningrad, 1973.

Bajkov B.N.; Kuchko W.S. Technical-and-Economic Assessment of Losses and Impoverishment in Mining Operations, Niedra Publishers, Moscow, 1974.

Bałaga D. Assessment of efficiency in reduction of dust concentration in mineral processing plants using the state-of-the-art technical measures. New Trends in Production Engineering, 2(1), 2019, pp. 11-19.

Biały W. Application of quality management tools for evaluating the failure frequency of cutter-loader and plough mining systems. Archives of Minning Sciences, Volume 62, issue 2, 2017. pp. 243-252. ISSN 0860-7001. DOI 10.1515/amsc-2017-0018.

Biały W. Coal cutting force measurment systems - (CCFM). 14th SGEM GeoConference on Science and Technologies In Geology, Exploration and Mining, SGEM2014 Conference Proceedings, June 17-26, 2014, Vol. III, BUŁGARIA ISBN 978-619-7105-09-4/ISSN 1314-2704. pp. 91-98, 2014.

Biały W. Determination of workloads in cutting head of longwall tumble heading machine. Management

Biały W. Innovative solutions applied in tools for determining coal mechanical proprerties. Management

Brzychczy E. Modelling and Optimization Method of Exploitational Activities in a Multi-Plant Mining Enterprise. Cracow. AGH Publishers. Series: Dissertations and Monograph No. 245, 2012.

Cohen R. A.; Patel A.; Green F. H. Lung disease caused by exposure to coal mine and silica dust. In Seminars in respiratory and critical care medicine (Vol. 29, No. 06, 2008, pp. 651-661). © Thieme Medical Publishers.

Dyczko A. Methodology for the assessment of the impact of out of seam dilution on the efficiency of hard coal production on the example of LW Bogdanka S.A. Doctoral thesis under scientific supervision of Prof. Roman Magda. AGH University of Science and Technology. Cracow, 2018.

Dyczko A.; Kopacz M. Influence of Impoverishment on Forming Characteristics of Mining Investment Projects and Selected Production Figures Exemplified by a Copper Deposit. 21st World Mining Congress. Cracow, 2008.

Figiel, A., Klačková, I. Safety requirements for mining complexes controlled in automatic mode. In Journal Acta Montanistica Slovaca 2020, Volume 25, 3; ISSN 1335-1788, DOI 10.46544/AMS.v25i3.13.
Finkelman R. B.; Orem W.; Castranova V.; Tatu C. A.; Belkin H. E.; Zheng B.; Bates, A. L. Health impacts of coal and coal use: possible solutions. International Journal of Coal Geology, 50(1-4), 2002, pp. 425-443.
Grudziński Z. Methods of Competition Assessment of Domestic Hard Coal for a Production of Electric Energy. IGSMiE Pan, Series: Studies, Dissertations and Monographs, No. 180, Cracow, 2012.
Grudziński Z. Proposals of Price Structures for Steam Hard Coal and for Lignite. Energy Policy Journal (Polityka Energetyczna) 2012 (2/2), Cracow, 2009, pp. 159-171.
Ingler D. Mining Methods, Rock Dilution and Ore Losses, 1984.
Kaplunov R.P Classification and Method of Determining Losses in Mining Ore Deposits. Gornyj Zhurnal (Mining Journal), No. 10, 1938.
Kaplunov R.P. Problems of Mining Industry. Uglietechizdat, Moscow, 1948.
Karbownik A. Grounds of Designing Theory. Selected Issues for Mining Faculties. Silesian Technical University. Gliwice, 1987.
Knissel W.; Jurgen H.; Fahlbusch M. Significance of Selective Mining Exploitation for Economical and Environmentally Beneficial Underground Ore Mining. International Mineral Resources Engineering, Imperial College Press 5, 2, 1955, pp. 165-174.
Kopacz M. The Impact Assessment of Quality Parameters of Coal and Waste Rock on the Value of Mining Investment Projects – Hard Coal Deposits Mineral Resources Management, Volume 31, Issue 4, 2015, pp. 5-30.
Kopacz M.; Kulpa J.; Galica D.; Dyczko A.; Jarosz J. Economic valuation of coal deposits–The value of geological information in the resource recognition process. Resources Policy, 63, 101450, 2019.
Kowol D.; Matusiak P. Improving the quality of hard coal products using the state-of-the-art KOMAG solutions in a pulsating jig nod. In IOP Conference Series: Materials Science and Engineering (Vol. 641, No. 1, p. 012004). IOP Publishing, 2019.
Kowol D.; Matusiak P. Testing the possibility of using a selective crushing process for selected types of hard coal. In IOP Conference Series: Materials Science and Engineering (Vol. 679, No. 1, p. 012011). IOP Publishing, 2019.
Kuric, I., Gorobchenko, O., Litikova, O., Gritsuk, I., Mateichyk, V., Bulgakov, M., Klačková, I. Research of vehicle control informative functioning capacity, In Conference; Machine Modelling and Simulations 2019, Liptovský Ján, IN IOP Conference Series: Materials Science and Engineering, Volume 776, 24th Slovak-Polish International Scientific Conference on Machine Modelling and Simulations - MMS 2019, 3-6 September 2019, Liptovský Ján, Slovakia
Kuric, I., Klačková, I., Nikitin, Y.R., Zajačko, I., Císar, M., Tucki, K. Analysis of diagnostic methods and energy of production systems drives, In Journal; Processes, MDPI, 9, 843, DOI.org/10.3390/pr9050843, 2021.
Kustra A.; Sierpińska M. Execution of budget and monitoring functions in the life cycle of exploitation seam in the coal mine. Mining Review. Vol. 69. No. 9, 2013, pp. 94-98.
Liaposhchenko, O., Pavlenko, I., Ivanov, V., Demianenko, M., Starynskyi, O., Kuric, I., Khukhryanskiy, O. Improvement of Parameters for the Multi-Functional Oil-Gas Separator of „HEATER-TREATER“ Type. In 2019 IEEE 6th International Conference on Industrial engineering and applications (ICIEA), Waseda Univ, Tokyo, Japan, 12 – 15. apríl 2019, pp. 66-71.
Lisowski A. Grounds of Economic Efficiency of Underground Exploitation of Deposits. Katowice-Warsaw. PWN Publishers, 2001.
Lorenz U. et al. Proposal of a New Steam Coal Selling Formula for Professional Power Sector. IGSMiE PAN Publishers. Series; Studies, Dissertations and Monographs. No. 112. Cracow, 2002.
Lubosik Z. Geo-Engineering and Economic Criteria of Hard Coal Exploitation from Residual Seam Lots. GIG Scientific Projects. Mining and Environment. No 3. Katowice, 2009.
Lutyński A. Methane, Dust and Noise Hazards in Mechanical Preparation Plants of Hard Coal Mines. Innovative Mechanization Techniques and Technologies. Monograph No. 16. Publisher: KOMAG Institute of Mining Technology, 2016, pp. 1-106.
Lutyński A. Prevention of methane, dust and noise hazards in preparation plants of coal mines. Innovative Mechanization Techniques and Technologies. Monograph No. 16. Publisher: KOMAG Institute of Mining Technology, 2017, pp. 1-126.
Magda R. et al. Rationalization of a Model and Size of Hard Coal Mines in Economic Conditions at the Beginning of XXI Century. AGH Publishers. Cracow, 2002.
Mielnikov N. W. Future Mining Operations. Gornyj Zhurnal (Mining Journal). No. 2. Moscow, 1974.
Mielnikov N. W. Rational Use of Mineral Deposits. Gornyj Zhurnal (Mining Journal) No. 1. Moscow, 1973.
Mikołajczyk U.; Bujak-Pietrek S.; Szadkowska-Stańczyk I. Exposure to Silica Dust in Coal Mining. Analysis based on Measurements made by Industrial Hygiene Laboratories over the years 2001–2005. Work Medicine, 61(3), 2010, pp. 287-297.

Noppe, M. The measurement and control of dilution in an underground coal operation. In Proceedings of the 5th mining geology conference. Bendigo, 2003.
Önder M.; Önder S.; Akdag T.; Ozgun F. Investigation of dust levels in different areas of underground coal mines. International Journal of Occupational Safety and Ergonomics, 15(1), 2009, p. 125-130.
Pivarčiová, E., Domnina, K., Ságová, S. (2019). Design of the construction and research of vibrations and heat transfer of mine workings. Acta Montanistica Slovaca, 24(1), pp. 15-24.
Popov G. The Working of Mineral Deposits. 2nd Edition, MPr Publishers, Moscow, 1971.
Prostański D. Empirical models of zones protecting against coal dust explosion. Archives of Mining Sciences, 2017, 62.
Prostański, D. Development of research work in the air-water spraying area for reduction of methane and coal dust explosion hazard as well as for dust control in the Polish mining industry. Mater. Sci. Eng, 427, 2018, 012026.
Przybyła H. I.; Chmiela A. Organization and Economics in Designing an Exploitation of Coal. Silesian Technical University Publishers. Gliwice, 2007.
Rajwa S. Impact of Selected Geo-Engineering Results on a Process of Production Preparation in Polish Hard Coal Mines. GIG Scientific Projects. Mining and Environment No. 4. Katowice, 2007.
Saeedi G.; Rezai B.; Shareiar K.; Oraee, K. Quantifying level of out-of-seam dilution for longwall mining method and its impact on yield of coal washing plant in Tabas coal mine. In Proceedings of the international seminar on mineral processing technology, Trivandrum, India, 2008, pp. 370-73.
Sobczyk E. J. Arduousness of Geological-and-Mining Conditions of Hard Coal and Its Impact on Deposit Management. Series: Studies, Dissertations and Monographs, No. 150, Publishers: IGSMiE PAN, Cracow, 2009.
Systems in Production Engineering 1(21)/2016. ISSN 2299-0461. pp. 45-54. DOI: 10.12914/MSPE-08-01-2016
Systems in Production Engineering 4(20)/2015. ISSN 2299-0461. pp. 202-209. DOI: 10.12914/MSPE-2-04-2015
Turek M. Costs Management System in a Hard Coal Mine in the Cycle of Coal Face Operation. Publishers: Difin. Warsaw, 2013.
Wiecek, D., Burduk, A., Kuric, I. The use of ANN in improving efficiency and ensuring the stability of the copper ore mining process. In Acta Montanistica Slovaca, Volume 24, Issue 1, pgs. 1 – 14, 2019.
Wodarski K.; Bijańska J. Assessment of Economic Efficiency and Exploitational Risk of Residual Deposits of Hard Coal. Scientific Books of the Silesian Technical University – Mining, Book No. 30. Gliwice, 2014.
Wright, E. A. Dilution and mining recovery-a review of the fundamentals, 1983.