The Extraction Forecast for a Hard Coal Mine

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Abstract

This publication presents a method for forecasting the annual amount of coal extraction for a mine. The forecast of extraction amount was based on data from an actual hard coal mine. It included an analysis of retrospective data on sales quantity, calculation of regression coefficients of the mathematical trend model and extraction amount for the next year. The planned extraction amount was corrected for the most probable forecast error. In addition, a forecast extraction plan for the analyzed mine was provided for individual months, in two variants.

Keywords: *forecast coal mining, time series*

1. Introduction

The functioning of a mine largely determines its extraction amount, which directly results from the market demand for coal. The changing level of demand, mainly with a downward trend, results in a decrease in the degree of utilization of the mine's extraction capacity, which in each case causes a more than proportional decrease in profit (operating leverage effect). This effect is more noticeable in the case of a significant share of fixed costs in the cost structure of the enterprise. In the case of the coal mining industry, we are dealing with such a situation at the level of 80%. The higher the share of fixed costs in the cost structure, the more important the full utilization of extraction capacity becomes, and not only of the mine, but of each enterprise. Hence, the pursuit of improving the economic and financial condition of mining, as part of restructuring programs, in particular consists in reducing excess extraction capacity in relation to the variable demand for coal. An additional factor determining the level of coal extraction amount is the seasonality of sales.

In certain months, excess extracted coal ends up in a dump, which results in mines being forced to bear the costs of storing and maintaining reserves of extracted coal. These costs include, among others, the costs of securing dumps, related salaries, supervision, property tax, and above all, the costs of freezing financial resources (cost of lost income).

It is also necessary to pay attention to another key aspect related to coal mining, namely the geological and mining conditions. They significantly determine the organization of the mining process. Generally speaking, it is necessary to carry out mining in a continuous manner, often with appropriate advancement of the wall (speed of extraction), roof management, etc.

Taking into account the above conditions of mine operation and at the same time striving to minimize the financial effects of the decrease in demand and seasonality of sales, the article presents a method of variant forecasting of the amount of coal extraction using the example of a real hard coal mine.

2. Analysis of the amount of coal extraction and sales of the Y mine

The basis for the analyses conducted in this publication are data from an actual hard coal mine. Its name has been changed for formal reasons and will be referred to hereinafter as mine Y. The numbering of the years analyzed has also been changed. Table 1 summarizes the annual amount of coal extraction and sales of mine Y in the years 20Y1–20Y7.

Analyzing the amount of coal extraction and its sales for the years 20Y1–20Y7 (Tab. 1), it can be seen that mine Y extracted more coal in the analyzed period than it sold, except for the year 20Y7 (Fig. 1). The total amount of coal that ended up on the dump in the analyzed period was 536,491 tons (the last column of Tab. 1 – Difference). The aim of developing a forecast of the extraction amount for the analyzed mine is to determine the level of extraction without accumulating excessive coal reserves.

The mining industry, which is involved in the exploitation of energy resources, is characterized by seasonality of sales. It results from periodic changes (decreases and increases) in the demand of recipients, i.e. producers of electricity and heat and individual recipients. This can be seen in the example of the years 20Y1 and 20Y2 (Fig. 2). Sales increase in the autumn-winter periods and decrease in the spring and summer periods.

3. The extraction forecast for a mine Y

The forecasting of the extraction amount is carried out based on retrospective data on the realized coal sales amount by the analyzed mine. The regression method was used to calculate the model value of the variable y (coal extraction amount). This method consists in selecting the analytical form of the function $y = ax + b$, which best describes the relationship between the sales amount and time, and in determining the degree of fit of the empirical line to statistical data. The classic least squares method is most often used for linear regression, but it can also be used for statistical determination of non-linear trend line parameters, including the trend: ex-

Tab. 1. The amount of the extraction and sale of coal by mines Y in the years 20Y1–20Y7. Source: own study based on internal materials of the Y mine

Tab. 1. Wielkość wydobycia i sprzedaży węgla przez kopalnię Y w latach 20Y1–20Y7. Źródło: opracowanie własne na podstawie materiałów wewnętrznych kopalni Y

Year	Amount		Difference [t]
	extraction [t]	sales [t]	
20Y1	1,480,691	1,469,703	10,988
20Y2	1,369,702	1,254,102	115,600
20Y3	1,254,101	1,137,812	116,290
20Y4	1,135,811	1,056,121	79,690
20Y5	1,094,119	914,014	180,106
20Y6	941,011	763,862	177,149
20Y7	729,859	873,189	-143,331
		Grand total	536,491

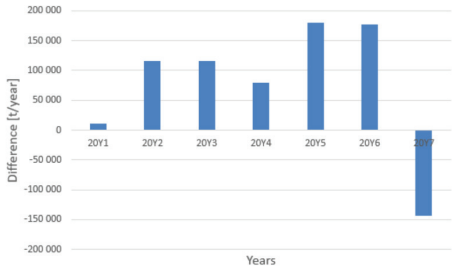

Fig. 1. The difference between the amount of the extraction and sale of coal mines Y in 20Y1–20Y7. Source: own study based on internal materials of the Y mine

Rys. 1. Różnica między wielkością wydobycia i sprzedaży węgla kopalni Y w latach 20Y1–20Y7. Źródło: opracowanie własne na podstawie materiałów wewnętrznych kopalni Y

Fig. 2. The sales amount of coal mines Y in years 20Y1 and 20Y2. Source: own study based on internal materials of the Y mine

Rys. 2. Wielkość sprzedaży węgla kopalni Y w latach 20Y1 i 20Y2. Źródło: opracowanie własne na podstawie materiałów wewnętrznych kopalni Y

ponential, hyperbolic, power-law, logarithmic, etc. The model is selected based on the value of the correlation coefficient. According to this method, the regression coefficients of the model are calculated based on the following formulas [3, 5]:

$$a = \frac{\sum(y_i - \bar{y}) \cdot (x_i - \bar{x})}{\sum(x_i - \bar{x})^2} \quad (1)$$

$$b = \bar{y} - a \cdot \bar{x} \quad (2)$$

In order to determine the strength of correlation between variables x (subsequent years of the analyzed period) and y (sales amount), and to assess the degree of fit of the regression line to empirical data, the linear correlation coefficient r is calculated [3, 5]:

$$r = \frac{\sum(y_i - \bar{y}) \cdot (x_i - \bar{x})}{\sqrt{\sum(x_i - \bar{x})^2 \cdot \sum(y_i - \bar{y})^2}} \quad (3)$$

Based on the time series, we determine the trend that fits the analyzed data and then extrapolate it to future years. The obtained sales amount for a specific forecast year should be corrected by the value of the forecast error. It is proposed to estimate the size of the forecast error based on the following formula [1, 2, 3, 4, 5]:

$$\sigma_{yprog} = \sqrt{\sigma_r^2 + \sigma_{\hat{y}}^2} \quad (4)$$

wherein:

σ^2_r – variance of the residual component, which is the standard error of estimating the regression function, being a measure defining the average deviations of the actual values of the explained variable from the theoretical values of this variable determined from the regression function. This is one of the parameters of the random component distribution, which allows us to conclude about the goodness of fit of the model to the empirical data. We calculate it from the formula:

$$\sigma_r^2 = \frac{\sum_{n=1}^{N}(y_n - y_{\text{mod}})^2}{N - K} \quad (5)$$

where:

y_n – actual value of endogenous factor;

y_{mod} – model-based value of endogenous factor;

N – number of observations;

K – number of estimating parameters for model structure.

$\sigma^2_{\hat{y}}$ – variance of the forecasting model calculated based on the dependence:

Tab. 2. Summary results of the regression analysis for the amount of coal sales for years 20Y1–20Y7

Tab. 2. Zestawienie wyników analizy regresji dla wielkości sprzedaży węgla za lata 20Y1–20Y7

Model	a	b	r
Linear	- 106,922.18	1,494,660.29	-0.949
Exponential	0.91	1,551,131.27	-0.948
Hyperbolic	740,692.11	792,613.17	0.923
Power-law	- 0.31	1,529,367.78	-0.952
Logarithmic	- 796,921.37	1,488,478.14	-0.974

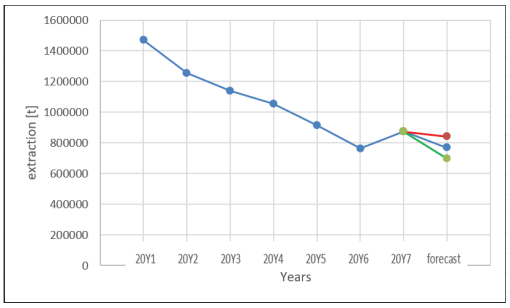

Fig. 3. Forecasted sales amounts of Y mine coal for 20Y8. Source: own study based on internal materials of the Y mine

Rys. 3. Prognozowane wielkości sprzedaży węgla kopalni Y na rok 20Y8. Źródło: opracowanie własne na podstawie materiałów wewnętrznych kopalni Y

Tab. 3. Sales amount of coal mines Y in different months 20Y1–20Y7 years

Tab. 3. Wielkość sprzedaży węgla kopalni Y w poszczególnych miesiącach lat 20Y1–20Y7

Months	20Y1	20Y2	20Y3	20Y4	20Y5	20Y6	20Y7
January	146,805	135,902	98,127	77,695	69,441	65,070	71,032
February	133,226	114,780	95,905	87,589	60,937	68,217	70,083
March	123,375	123,536	96,667	104,821	63,395	41,868	74,648
April	112,373	86,588	85,784	87,040	82,005	77,209	67,169
May	108,932	103,489	95,021	89,635	90,337	58,810	65,687
June	120,322	107,220	92,747	100,269	86,698	58,527	54,895
July	130,380	105,993	99,911	85,082	70,818	55,228	68,675
August	96,400	89,248	105,559	88,907	45,041	50,285	60,415
September	120,863	116,695	87,450	85,022	73,255	68,325	74,457
October	125,088	100,841	102,492	98,372	97,487	81,649	94,431
November	123,377	83,743	102,492	89,515	106,410	75,008	103,526
December	128,563	86,068	75,658	62,175	68,192	63,667	68,172
Grand total	1,469,703	1,254,102	1,137,812	1,056,121	914,014	763,862	873,189

$$\sigma_{\hat{y}}^2 = \begin{bmatrix} 1 & x_{N+1} \end{bmatrix} \cdot \left[X^T \cdot X \right]^{-1} \cdot \begin{bmatrix} 1 & x_{N+1} \end{bmatrix}^T \cdot \sigma_r^2 \quad (6)$$

where:

x_{N+2} – time, during which prognosis is prepared.

and

$$X = \begin{bmatrix} 1 & x_1 \\ 1 & x_2 \\ 1 & x_3 \\ \hline 1 & x_N \end{bmatrix}, \quad X^T X = \begin{bmatrix} N & \sum_{n=1}^{N} x_n \\ \sum_{n=1}^{N} x_n & \sum_{n=1}^{N} x_n^2 \end{bmatrix} \quad (7)$$

Based on the data presented in Table 1 and formulas (1)-(3), five models were used to examine the development of coal sales amounts in the Y mine in the years 20Y1–20Y7. The calculation results are presented in Table 2. The best model turned out to be the logarithmic model with a correlation coefficient of -0.974:

y = -796,921.37 x + 1,488,478.14

The estimated sales amount for 20Y8 based on this equation, which in effect constitutes the planned coal extraction amount, was 768,786 tons. The standard deviation of the residual component was then determined using formula (5):

σ_r = 54,947.72 [t]

The forecast error calculated based on formula (4) was:

σ_{yprog} = 71,943.45 [t]

The forecasted coal sales amount for mine Y for 20Y8 was 768,786 ± 71,943.45 tonnes. The calculated forecast error is approximately 5% of the forecast value. Providing an exact forecast value for 20Y8 requires adding or subtracting the error from the model value. Analyzing the course of retrospective data (Fig. 3), it can be stated that both adding and subtracting the error fits into the downward trend of coal sales. It seems more likely and logical that the forecast value for 20Y8 should be 696,843 tonnes than 840,730 tonnes, which results from the significant annual decrease.

When analyzing annual coal sales values, sales fluctuations (seasonality) in relation to individual months of the year are not taken into account. Sales realized in specific months (Tab. 3) could have followed different (for each month) trends. According to the author, the forecast calculation for a

Tab. 4. Summary results of regression analysis for coal sales volumes by month

Tab. 4. Zestawienie wyników analizy regresji dla wielkości sprzedaży węgla w poszczególnych miesiącach

	MODEL	a	b	r
January	Linear	-14,202.46	151,677.29	-0.912
	Exponential	0.87	159,762.41	-0.925
	Hyperbolic	101,185.26	57,387.58	0.912
	Power-law	-0.46	158,939.50	-0.954
	Logarithmic	-108,405.53	152,205.13	-0.958
February	Linear	-11,340.11	135,465.71	-0.922
	Exponential	0.89	141,671.09	-0.914
	Hyperbolic	80,561.64	60,264.60	0.919
	Power-law	-0.39	140,575.43	-0.936
	Logarithmic	-86,035.04	135,610.82	-0.963
March	Linear	-12,242.46	138,728.43	-0.853
	Exponential	0.86	151,524.27	-0.797
	Hyperbolic	74,649.63	62,107.74	0.730
	Power-law	-0.44	144,774.09	-0.765
	Logarithmic	-86,543.39	135,532.99	-0.831
April	Linear	-5,648.18	108,045.29	-0.884
	Exponential	0.94	109,631.47	-0.903
	Hyperbolic	42,293.93	69,786.55	0.929
	Power-law	-0.21	109,031.45	-0.921
	Logarithmic	-42,998.29	108,195.17	-0.927
May	Linear	-7,992.04	119,384.00	-0.926
	Exponential	0.91	125,768.84	-0.900
	Hyperbolic	45,984.51	70,382.82	0.748
	Power-law	-0.28	120,145.52	-0.826
	Logarithmic	-54,223.55	116,095.71	-0.866
June	Linear	-10,704.14	131,484.86	-0.951
	Exponential	0.88	143,669.51	-0.934
	Hyperbolic	63,380.72	65,191.55	0.790
	Power-law	-0.37	134,839.55	-0.854
	Logarithmic	-73,217.64	127,394.46	-0.895
July	Linear	-11,276.36	133,117.86	-0.942
	Exponential	0.88	141,252.97	-0.934
	Hyperbolic	77,851.70	59,175.52	0.913
	Power-law	-0.40	138,313.61	-0.932
	Logarithmic	-83,934.68	132,407.05	-0.965
August	Linear	-8,799.96	111,750.57	-0.788
	Exponential	0.89	118,666.70	-0.768
	Hyperbolic	47,103.07	59,103.35	0.592
	Power-law	-0.35	112,324.48	-0.709
	Logarithmic	-58,405.71	107,442.58	-0.720
September	Linear	-8,934.04	125,174.29	-0.912
	Exponential	0.91	128,612.85	-0.921
	Hyperbolic	62,372.21	66,334.97	0.894
	Power-law	-0.31	127,880.04	-0.945
	Logarithmic	-67,461.59	125,119.83	-0.948
Oktober	Linear	-4,834.29	119,388.57	-0.804
	Exponential	0.95	119,904.38	-0.803
	Hyperbolic	38,888.04	85,646.98	0.907
	Power-law	-0.16	120,761.98	-0.868
	Logarithmic	-38,572.04	120,452.90	-0.883
November	Linear	-2,610.89	108,168.00	-0.349
	Exponential	0.98	106,865.11	-0.327
	Hyperbolic	30,792.70	86,318.55	0.577
	Power-law	-0.11	109,951.34	-0.436
	Logarithmic	-25,587.01	111,257.88	-0.470
December	Linear	-8,337.18	112,276.57	-0.772
	Exponential	0.91	111,143.49	-0.793
	Hyperbolic	75,627.93	50,914.66	0.982
	Power-law	-0.34	116,085.29	-0.922
	Logarithmic	-71,536.16	116,764.67	-0.911

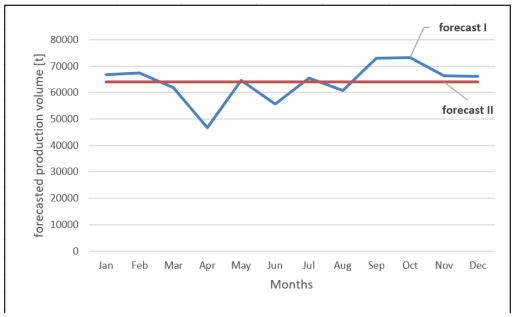

Fig. 4. Variants of extraction forecast for the mine Y

Rys. 4. Warianty prognozy wydobycia dla kopalni Y

Tab. 5. Summary of regression coefficients and forecasts the amount of extraction coal mine Y in different months of year 20Y8

Tab. 5. Zestawienie wariantów prognoz wielkości wydobycia węgla dla kopalni Y w poszczególnych miesiącach roku 20Y8

Months	model sales	σ_{yprog}	Forecast	
			Variant I	Variant II
January	54,305.07	12,563.39	66,868.45	64,034.40
February	57,913.44	9,419.52	67,332.97	64,034.40
March	40,788.71	21,151.66	61,940.37	64,034.40
April	75,073.30	28,251.81	46,821.49	64,034.40
May	55,447.71	9,174.35	64,622.07	64,034.40
June	45,851.71	9,887.18	55,738.90	64,034.40
July	56,606.48	8,846.43	65,452.91	64,034.40
August	41,350.86	19,450.91	60,801.77	64,034.40
September	64,195.95	8,793.57	72,989.52	64,034.40
October	90,507.99	17,158.21	73,349.78	64,034.40
November	90,167.65	23,801.85	66,365.80	64,034.40
December	60,368.15	5,760.62	66,128.77	64,034.40
Grand total			768,412.79	768,412.79

specific month will be more accurate than for the entire year. Therefore, it was decided to estimate the extraction amount for mine Y for the year 20Y8 broken down into individual months. For this purpose, trend functions for individual months of the analyzed years were adjusted based on the correlation coefficient (Tab. 4), and then sales forecasts were calculated for the subsequent months of the year 20Y8 (Tab. 5, Fig. 4). For each model monthly (forecasted) sales amount, the forecast error σ_{yprog} was calculated and corrected, thus creating forecast variant I. Considering the maintenance of continuity and rhythm (geological and mining conditions) of coal extraction, forecast variant II can be considered. This variant assumes uniform extraction throughout the year (Tab. 5, Fig. 4).

3. Conclusion

Forecasting extraction amount is inherently burdened with error. On the other hand, operating without planning extraction amount in relation to market demand will entail losses. These losses are related, among others, to excess extraction, for which there are no recipients and which is stored in the warehouse. The issues presented in this publication allow us to state that relatively simple forecasting methods allow for minimizing the amount of coal that would end up on the dump, and thus minimizing the costs associated with it. It should be emphasized that the mining industry, unlike other industries, is characterized by specific operating conditions. The mining process is determined primarily by mining and geological conditions, which forces mines to maintain continuity and rhythm of coal extraction. Therefore, the proposed variant II of the forecast (even extraction) is more appropriate for the mining industry extracting hard coal. Coal reserves accumulated on dumps in the spring and summer period would be sold at the end of the year.

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Prognoza wielkości wydobycia dla kopalni węgla kamiennego

W niniejszej publikacji przedstawiono sposób prognozowania rocznej wielkości wydobycia węgla dla kopalni. Prognozę wielkości wydobycia przeprowadzono w oparciu o dane rzeczywistej kopalni węgla kamiennego. Obejmowała ona analizę danych retrospektywnych dotyczących wielkości sprzedaży, obliczenie współczynników regresji modelu matematycznego trendu oraz wielkość wydobycia na rok przyszły. Planowana wielkość wydobycia została skorygowana o najbardziej prawdopodobny błąd prognozy. Ponadto podano prognozowany plan produkcji dla analizowanej kopalni w odniesieniu na poszczególne miesiące, w dwóch wariantach.

Słowa kluczowe: *prognoza wydobycia węgla, szeregi czasowe*