AGH Journal of Mining and Geoengineering • vol. 36 • No. 3 • 2012

*Dariusz Fuksa**

THE METHOD OF THE ANALYSIS OF THE COAL RESERVES LEVEL IN A MINING ENTERPRISE FOLLOWING THE VARIABLE USER DEMAND**

1. Introduction

The seasonal character of coal sales, occurring during the characteristic seasons of the year, results in accumulation of reserves of coal. The coal-spoil heaps thus forming, expose mines to the risk of incurring costs of storing and holding of surplus of coal. These costs, first and foremost, include the costs of securing the heaps, remuneration related therewith, supervision, real estate tax as well as the cost of freezing of financial means (the cost of lost income). And for this reason precisely, it is necessary to embark on activities enabling mining enterprises to advantageously get rid of excessive coal reserves. One of such solutions can have the form of offering coal users quantity and „on payment" discounts. These tools facilitate the levelling of negative financial phenomena such as outdated receivables or bad debts. A rational policy in the area of receivables management allows the enterprise to define the type and value of discounts to be given to users in order to maintain financial liquidity on the required level.

The presented method of analysis of the impact of the variability of coal users demand on the level of reserves of a mining enterprise allows to assess the probability of occurrence of reserves of specific coal assortments as well as to establish whether new reserves, resulting from the lack of sales of the offered amounts of coal, will form. The user demand scenarios subject to the analysis reflect real situations possible to occur, hence the results of conducted analyses can constitute useful information in planning annual production values for mines.

* AGH University of Science and Technology, Krakow
** This study is supported through the statutory research registered in AGH University of Science and Technology in Krakow at No. 11.11.100.481.

2. The characteristics of the proposed method

The basis for conducting the analysis of the impact of the variable coal user demand on the coal reserve level of a mining enterprise and the mines it comprises is formed by a set of optimal solutions in terms of the task of optimisation of production and sales of coal. This set is created with the use of the Monte Carlo method [3, 9, 10]. It is achieved by means of multiple setting of the optimum coal production and sales programme at the assumed, random user demand scenario. The optimal solutions are achieved using the SIMPLEX algorithm.

To draw the demand value vector for all groups of users, a games of chance generator is used. The drawn demand vector is a set of sub-vectors of the right sides of the condition (2) of the developed model for optimising the quantitative and qualitative structure of hard coals extraction [4]. This condition has the following form:

$$\sum_{i=1}^{r_j}\sum_{j=1}^{p}\sum_{k=1}^{m_{ij}} x_{ijk_n} \le Z_k \quad \text{for all } k, \tag{1}$$

where:

- x_{ijk} — net amount of extracted coal of ij type accepted by consumers in group k, netto tone,
- Z_k — consumer demand for group k, ton,
- i — index of coal type, $i = 1, 2, 3, ..., r_j$,
- j — index of mine, $j = 1, 2, 3, ..., p$,
- k_n — index of consumer groups, $k = 1, 2, 3, ..., m_{ij}$, where m_{ij} marks numerousness miscellany k_n for coal of i_j type.

The remaining limitations related to the structure of production and production capacity of individual mines as well as the optimisation model have been extensively discussed in works [4]. Each time, the demand vector Z, being a random variable with normal distribution with the expected value equal to the planned demand value, is drawn. The most probable model error is adopted for dispersion (a standard deviation). In each case, new coal production and sale programmes are obtained. On their basis, it is possible to present the results of the analysis in the form of histograms of the level of reserves for the entire mining enterprise and to determine the probability of achieving the assumed reserve level.

3. Computations and assessment of obtained results

The computations were carried out for a mining enterprise consisting of six mines with a varied production characteristics. The production capacity along with the technical and economic indicators of the mines under analysis are presented in Table 1.

TABLE 1

Technical and economic coefficients for mines „A"–„D"

Specification	Unit	Mines			
		„A"	„B"	„C"	„D"
Average Extraction	ton/day	6,200	10,500	19,500	10,200
Max. Extraction	netto ton	1,600,000	2,700,000	5,100,000	2,600,000
Unit cost	PLN/ton	136.9	159.02	153.75	192.53
Fixed cost	%	76.6	86.96	85.71	81.2

To draw the demand values of specific user groups, at the first stage, a normal distribution was adopted with the expected value equal to the realised demand (sales) value in 2011. The most probable (standard) error of the forecast was adopted for dispersion. The value of the dispersion σ_{yprog} was estimated based on the formula below [1–2, 5–8]:

$$\sigma_{yprog} = \sqrt{\sigma_r^2 + \sigma_{\hat{y}}^2} \tag{2}$$

whereby σ_r — the variation of the remainder factor obtained with the following equation:

$$\sigma_r^2 = \frac{\sum_{n=1}^{N} \left(y_n - y_{\text{mod}}\right)^2}{N - K} \tag{3}$$

where:

- y_n — actual value of endogenous factor, ton,
- y_{mod} — model-based value of endogenous factor, ton,
- N — number of observations,
- K — number of estimating parameters for model structure.
- $\sigma_{\hat{y}}^2$ — estimation of variance in prognosis model:

$$\sigma_{\hat{y}}^2 = \begin{bmatrix} 1 & x_{N+2} \end{bmatrix} \cdot \left[X^T \cdot X\right]^{-1} \cdot \begin{bmatrix} 1 & x_{N+2} \end{bmatrix}^T \cdot \sigma_r^2 , \tag{4}$$

where x_{N+2} — the time for which the prognosis is prepared and

$$X = \begin{bmatrix} 1 & x_1 \\ 1 & x_2 \\ 1 & x_3 \\ \hdashline 1 & x_N \end{bmatrix}, \qquad X^T X = \begin{bmatrix} N & \sum_{n=1}^{N} x_n \\ \sum_{n=1}^{N} x_n & \sum_{n=1}^{N} x_n^2 \end{bmatrix} \tag{5}$$

The number of draws equal 1,000 was adopted. At the second stage, the nominal value of the forecast of demand for each user was decreased (P_1) in the first case and in the second — increased (P_2) by the model error value.

Table 2 presents annual forecast values and dispersion of demand of individual user groups whereas the results obtained with the use of the proposed method are presented in Table 3 and in Figures 1–3. The black vertical line visible in the figures illustrates the reserve level resulting from the optimum plan of coal production and sales for the mines and for the mining.

TABLE 2

Nominal prognosis value and dispersion σ_{yprog} for every group of consumers [ton]

Name of consumer group	Nominal prognosis values	Dispersion σ_{yprog}	Nominal value of prognosis P_1	Nominal value of prognosis P_2
Export 8	300,857	70,205.89	230,651.11	371,062.89
Export 9	419,447	116,913.60	302,533.40	536,360.60
Indv. consumers 1	336,060	10,565.02	325,494.98	346,625.02
Indv. consumers 3	5,475,600	140,552.80	5,335,046.20	5,616,151.80
Indv. consumers 4	1,391,200	35,710.60	1,355,489.40	1,426,910.60
Dust kettles	2,385,300	61,228.09	2,324,071.91	2,446,528.10
Grates 2	265,940	6,826.40	259,113.60	272,766.40
Grates 3	1,095,000	28,107.22	1,066,892.78	1,123,107.20
Grates 4	567,619	14,570.20	553,048.80	582,189.20
Chamber grates 1	425,765	10,928.80	414,836.20	436,693.80

TABLE 3

Specification of the planned, minimum, maximum, and average value of the reserve level obtained by means of the developed method as well as the probability of reaching it for the planned values P_1 and P_2 and dispersion σ_{yprog}

	Predicted reserve level [t]				Probability of reaching the reserve level [–]			
	According to the plan	Min	Max	Average	Min	Max	According to the plan	Average
Mine „A”								
nut coal								
σ_{yprog}	0	0	31,974	96	0.997	0.003	1.000	0.003
P_1	0	0	0	0	1.000	1.000	1.000	1.000
P_2	0	0	0	0	1.000	1.000	1.000	1.000

TABLE 3 cd.

	Predicted reserve level [t]				Probability of reaching the reserve level [–]			
	According to the plan	**Min**	**Max**	**Average**	**Min**	**Max**	**According to the plan**	**Average**
Mine „A”								
pea coal								
σ_{yprog}	0	0	47,973	439	0.003	0.985	1.000	0.015
P_1	0	0	5,286	16	0.989	0.008	1.000	0.011
P_2	0	0	86,045	538	0.985	0.003	1.000	0.015
fine coal II								
σ_{yprog}	401,740	0	742,400	356,303	0.062	0.020	0.458	0.568
P_1	401,740	0	662,701	51,112	0.649	0.003	0.020	0.286
P_2	401,740	0	742,400	556,938	0.003	0.137	0.868	0.572
slurry								
σ_{yprog}	25,109	0	46,400	23,652	0.033	0.044	0.493	0.555
P_1	25,109	0	41,419	3,370	0.620	0.003	0.020	0.323
P_2	25,109	13,473	46,400	43,530	0.003	0.693	0.982	0.747
Mine „B”								
fine coal II-19/30								
σ_{yprog}	923,400	570,767	923,400	912,989	0.003	0.911	0.911	0.917
P_1	923,400	581,405	923,400	895,152	0.003	0.842	0.842	0.857
P_2	923,400	204,100	923,400	923,400	0.003	0.894	0.894	0.902
Mine „C”								
fine coal II-19/23								
σ_{yprog}	0	0	229,107	1,185	0.981	0.002	1.000	0.019
P_1	0	0	594,438	82,699	0.486	0.002	1.000	0.382
P_2	0	0	0	0	1.000	1.000	1.000	1.000
Mine „D”								
nut coal								
σ_{yprog}	0	0	12,599	54	0.944	0.003	1.000	0.006
P_1	0	0	96,556	1,803	0.948	0.003	1.000	0.052
P_2	0	0	0	0	1.000	1.000	1.000	1.000
pea coal								
σ_{yprog}	0	0	0	0	1.000	1.000	1.000	1.000
P_1	0	0	37,995	186	0.984	0.003	1.000	0.016
P_2	0	0	0	0	1.000	1.000	1.000	1.000
fine coal II-19/23								
σ_{yprog}	7,380	0	46,534	10,321	0.329	0.003	0.548	0.465
P_1	7,380	0	61,104	22,327	0.061	0.003	0.853	0.535
P_2	7,380	0	31,964	2,998	0.692	0.003	0.156	0.271

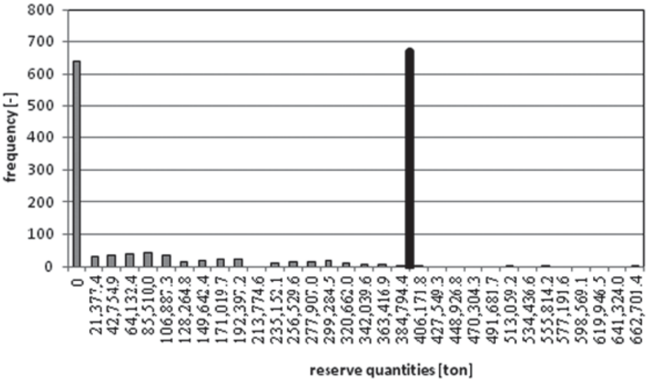

Fig. 1. The histogram of frequency of obtained fine coal II assortment reserve quantities for mine „*A*" with the planned value P_1 and dispersion σ_{yprog}

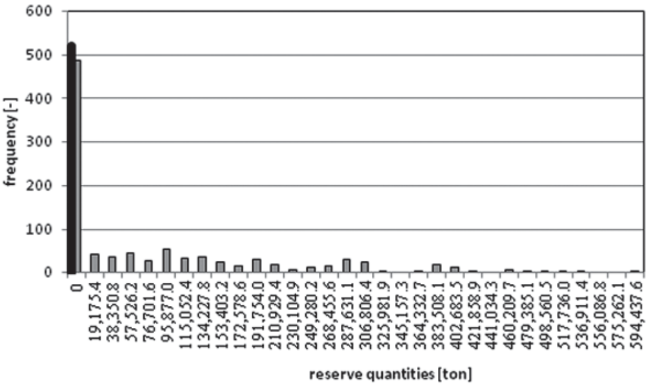

Fig. 2. The histogram of frequency of obtained fine coal II assortment reserve quantities for mine „*C*" with the planned value P_1 and dispersion σ_{yprog}

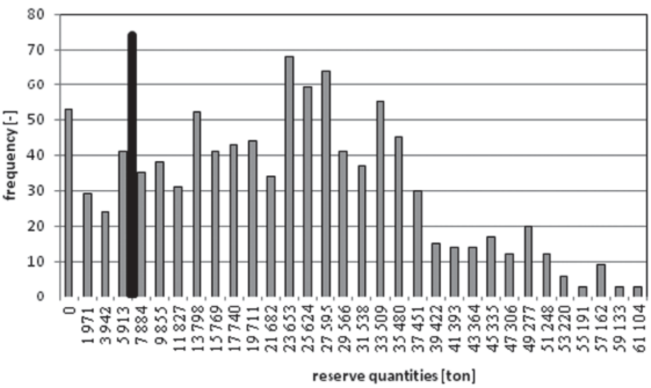

Fig. 3. The histogram of frequency of obtained fine coal II–19/23 assortment reserve quantities for mine „*D*" with the planned value P_1 and dispersion σ_{yprog}

Based on the conducted analysis, the following conclusions can be arrived at:

1) The coal production and sales plan for mine „*A*” did not provide for the reserves of nut coal and pea coal assortments. Despite that, the probability of occurrence of reserves of these assortments is only very small. Whereas the quantity of fine coal II assortment reserves at dispersion σ_{yprog} shall be lower than the one demonstrated in the optimum plan (Tab. 3, Fig. 1). For demand level P_1, fine coal II assortment reserves shall not occur whereas for demand level P_2, there is high probability (0.868) that the reserves shall be maintained at the level as in the optimum plan. The situation of the slurry assortment reserves shall be similar.
2) There is high probability that the quantity of fine coal II–19/30 assortment (with the maximum ash content of 30%) reserves for mine „*B*”, in the demand variants subject to the analysis, will be equal to the average quantity, slightly lower than one disclosed in the production and sales plan whereas in the case of the demand level P_2, it will be equal to the quantity in the plan.
3) The quantity of fine coal II reserves in mine „*C*” shall not occur with high probability for σ_{yprog}, and P_2. Whereas in the case of a lower demand level (P_1), there is probability of more than 0.4 that this assortment will be dumped on a heap (Tab. 3, Fig. 2).
4) The chances for nut coal and pea coal assortment reserves in mine „*D*” are very low – probability equal to or almost equal to 1. Whereas the quantity of fine coal II–19/23 assortment reserves is characterised by large fluctuations against the volatility of demand. The quantity of 7,380 ton will be held with the probability exceeding 0.5 for σ_{yprog} and P_2 and with the probability of 0.853 for P_1 (Tab. 3, Fig. 3). However, attention must be drawn to the fact that for the demand level P_2, with the probability of 0.27, almost 3,000 ton will be dumped on a heap.
5) The user demand variants under analysis did not reveal a possibility of occurrence of reserves of coal in mine „*E*”.

4. Summary

The amount of the demand of potential and future users has a deciding impact on the efficiency of the functioning of a mining enterprise as well as a mine. Not adjusting the qualitative-quantitative structure of coal production to the requirements of the users as well as the seasonality of sales leads to the occurrence and collection of coal reserves. The obtained results allow for a direct indication as to which types of coal assortments can increase reserves and with what probability. As a result, this information may be considered in the planning of production, i.e.: decrease it by the amount of the most probable amount of reserves of a given assortment. The presented analysis method may constitute a helpful tool supporting the management staff in taking rational production decisions.

REFERENCES

[1] *Barnett V.*: Elementy pobierania prób. PWN, Warszawa, 1982.
[2] *Brandt S.*: Analiza danych. Metody statystyczne i obliczeniowe. PWN, Warszawa, 1998.
[3] *Buslenko N.*: Metoda Monte Carlo. PWN, Warszawa, 1967.
[4] *Fuksa D.*: Analiza postoptymalna jako metoda racjonalizacji decyzji produkcyjnych w spółce węglowej. Praca doktorska, Kraków, 2003.
[5] *Gnot S.*: Estymacja komponentów wariancyjnych w modelach liniowych. WNT, Warszawa, 1991.
[6] *Goryl A., Jędrzejczyk Z.*: Wprowadzenie do ekonometrii w przykładach i zadaniach. PWN, Warszawa, 1996.
[7] *Grabiński T., Wydymus S., Zaliaś A.*: Metody doboru zmiennych w modelach ekonometrycznych. PWN, Warszawa, 1982.
[8] *Rocki M.*: Ekonometria praktyczna. SGH, Warszawa, 2002.
[9] *Sadowski W.*: Teoria podejmowania decyzji. PWE, Warszawa, 1976.
[10] *Zieliński R.*: Metoda Monte Carlo. WNT, Warszawa, 1974.