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## **WORK EFFICIENCY DECREASE IN MINING AND PROCESSING**

### **Introduction**

The efficiency increase of production in mining is desired on the competitive markets of market economy. However, that objective is significantly limited by the specific features of mining and unique and changeable conditions that take place in the course of mining production processes. Production processes include mining and processing, and the specific and changeable conditions are decisive as regards an objective differentiation of the work efficiency level and unit costs in the conditions of particular mines. The differences, which are objective from the point of view of the necessity to adjust methods, technology and production organization to the natural geological and mining conditions in particular mines, result in the demand for monitoring and controlling the mining and processing operations with the view to achieve a required increase of efficiency. In order to analyze the features of a production process - hence, its progress – both retrospective and prospective methods can be used. The range of the application of the methods depends on the possibilities to monitor the processes under investigation and to process the data obtained. In prospective methods historical data are applied to assess and predict the indicators under analysis, and their aim is to “acquire not only the most possibly current data as regards the factual values of particular indicators, but also the information about their values in the nearest future”<sup>1</sup>. In the retrospective methods, the *post factum* approach results in the delay of the analysis results, while *on-line* methods enable a direct acquisition of the analysis results in real time. A quicker access to the analysis results makes it possible to react promptly to disturbances that occur in the production process. Not all values that describe the mining and processing processes can be analyzed with the application of *on-line* or prospective methods. The analysis using a *post-factum* method frequently provides fully satisfactory results; for example work efficiency – the basic indicator measuring human efficiency in mining and processing - is the value successfully analyzed with such methods. It is crucial that a post

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<sup>1</sup> Z. Pawłowski, *Ekonometryczna analiza procesu produkcyjnego*, PWN, Warszawa 1976, p. 31.

factum method used to identify the requirements and possibilities of work efficiency increase in particular stages of the mining and processing process under investigation makes it possible to determine an efficient course of action and to manage it. The investigation and analysis of the efficiency decrease function is of particular significance in this respect and the aim of the paper is to focus on this issue.

## 1. Efficiency versus labor consumption

With the aim to measure human efficiency in production processes, two notions are applied:

- work efficiency
- labor consumption.

Labor efficiency is defined by general relationship:

$$w = \frac{P}{T}, \quad (1)$$

where:

$w$  – labor efficiency,

$P$  – output,

$T$  – amount of human labor.

Depending on the output  $P$  measures applied, there are quantitative and qualitative work efficiency measures. In the quantitative approach work efficiency, when expressing the output, is given in physical units, such as pieces, tons or meters. The qualitative approach of the output enables the determination of qualitative measures of work efficiency. The quantitative expression of the output in mining may be given in number of tons (Mg) or kilograms of:

- gross or net output (hard coal mining),
- the concentrate obtained, of metal in the ore or in the concentrate (ore mining).

Pojęcia wydobywania brutto oraz wydobywania netto, stosowane w górnictwie węgla kamiennego dotyczą odpowiednio liczby ton (Mg) lub kg:

The notions of gross or net output that are applied in hard coal mining refer to the number of tons (Mg) or kilograms of:

- the raw coal transported to the surface – the gross output,
- the commercial coal, processed at the last production stage in the mine – the net output.

The qualitative approach to the output in a given period, with the basis on quantitative approach, applies current or comparable (for calculation purposes) unit prices. Moreover, in the general approach, the output gained in a given period is characterized by such measures as:

- total output,
- commercial output,
- sold output.

Przez produkcję globalną rozumie się całkowity rezultat pracy w danym okresie, przy czym na jej poziom, zarówno w ujęciu ilościowym, jak i wartościowym składają się:

Total output is the total effect of work in a given period and its level – both in the quantitative and qualitative approach – includes:

- commercial output, i.e. it can be subject to sales (it constitutes a commodity),
- the stocktaking difference of current production.

The sold output (earnings), determined qualitatively, is constituted by the commercial output in a given period reduced by the output that could be sold but was not in a given period or increased by the stock sold.

The amount of human labor  $T$ , given in the denominator of the general relationship, can be expressed by the number of:

- workdays,
- employees

that are indispensable to reach output  $P$  in a given period.

The application of the above mentioned options of measuring the amount of human labor  $T$  makes it possible to determine both the qualitative and the quantitative measures of work efficiency per a period under investigation, a workday or an average employee when reaching output  $P$ .

The notion of labor consumption is closely related to work efficiency. It describes the amount of human labor required by particular activities, work posts or processes. Mathematically it is given by relationship:

$$ch = \frac{1}{w} = \frac{T}{P}, \quad (2)$$

where:

$ch$  - labor consumption,

$w$  – work efficiency,

$P$  – output,

$T$  – amount of human labor.

Labour consumption index (2) , in comparison to efficiency index (1) has an additional advantage as it offers the possibility to add simply the labor consumption of particular operations, activities or technological processes that can be isolated within the production process under analysis. For example, when analyzing three stands passed by output  $P$ , when the total number of workdays  $D$  is the sum of workdays at particular stands ( $D = D_1 + D_2 + D_3$ ), the labor consumption of particular stands is given by the following relationships:

$$ch_1 = \frac{D_1}{P}, \quad (3),$$

$$ch_2 = \frac{D_2}{P}, \quad (4),$$

$$ch_3 = \frac{D_3}{P}, \quad (5),$$

zaś łączna pracochłonność trzech stanowisk wynosi:

and the total labor consumption of the three stands is :

$$ch = \frac{D}{P} = \frac{D_1 + D_2 + D_3}{P} = ch_1 + ch_2 + ch_3 \quad (6)$$

The operations on work efficiency indexes is not so easy as the total efficiency of the three stands will be:

$$w = \frac{P}{D} = \frac{P}{D_1 + D_2 + D_3} = \frac{1}{\frac{D_1}{P} + \frac{D_2}{P} + \frac{D_3}{P}} = \frac{1}{\frac{1}{w_1} + \frac{1}{w_2} + \frac{1}{w_3}} \quad (7)$$

## 2. Characteristic features of production processes in mining

Mining, as opposed to other industry branches, deals rather with the acquisition of raw materials than transforming them and the production processes in mining refer to the excavation and preparation in the unique mining conditions. The conditions and the production process itself are characterized by:

- close dependence of the mine location on the deposit localization;
- long investment cycles and specific mine development stages;
- variable and unpredictable mining conditions;
- constant decrease of the deposit;
- constant transfer of mining activities and the resulting necessity to conduct preparation and development work;

- significant amount and the unique character of auxiliary work – ventilation, dewatering, excavations maintenance;
- significant demand for power and facilitating materials;
- mass production;
- characteristic nature of work safety issues;
- mining damages issues;

The above listed features create a specific structure of production costs and a differentiation of work efficiency levels and unit costs in mines, which results from various natural geological and mining conditions.

The geological and mining conditions in particular mine are decisive as regards the choice of methods, technology and organization of subsequent stages of the production-preparation process, i.e. deposit exploitation (mining operations in particular coal faces and the haulage of the winning), horizontal and vertical transport and the preparation plan. Thus, the natural conditions in particular mines that are decisive as regards the opportunity to mechanize and automatize mining production processes determine significantly the level of obtainable work efficiency indexes and, what is more, have a substantial impact on the quality of the raw material mined; consequently, it is the conditions that decide on the commercial effectiveness of production processes in mining.

From the point of view of work efficiency analysis and the possibilities to stimulate its growth, it is important to identify:

- work efficiency increase factors,
- the most labor consuming stage of the production process.

The most fundamental factors of the efficiency growth are shown by general relationship (1)

$$w = \frac{P}{T} = \frac{P}{S_t} \cdot \frac{S_t}{T}, \quad (8)$$

where:

$S_t$  – value of fixed assets,

$\frac{P}{S_t}$  – productivity index of fixed assets,

$\frac{S_t}{T}$  – technical equipment ratio,

$w$  – work efficiency,

$P$  – output,

$T$  – amount of human labor.

It is clear that the increase of the work efficiency index can be achieved without investments by the growth of the productivity of fixed assets or with the application of adequate investments, which result in the increase of the technical equipment ratio. The non-investment approach, based on stimulating the productivity increase of fixed assets is a particularly desired opportunity to increase work efficiency. However, production processes in mining require technological progress, which results in the increase of technical equipment of work. Thanks to the mechanization and automation of mining processes, particularly troublesome and dangerous activities can be eliminated. Hence, it is of crucial importance in the mining industry to maintain adequate relationship between the pace of fixed assets productivity growth and the technical equipment ratio. The relationship should consider both the technical and organizational developments, which are decisive as regards the possibilities of the economic efficiency increase in mining. In the case of mass mining production, being the effect of realization of subsequent production stages, the identification of the area where the whole set of technological and organizational activities is to take place is also important in respect to the work efficiency increase. Such identification is enabled by the analysis using the curves of the efficiency decrease in the conditions of particular mines. In order to investigate the curves of efficiency decrease and labor consumption increase resulting from the realization of subsequent stages of the production process, the knowledge is applied about the percentage contribution of workdays  $D_n$  in particular stands or working activity in relation to the total number of workdays in the mine  $D_{kop}$ . For particular stands or working activities the percentage contribution of workdays  $\lambda_n$  is determined by general relationship:

$$\lambda_n = \frac{D_n}{D_{kop}} \cdot 100, \quad (9)$$

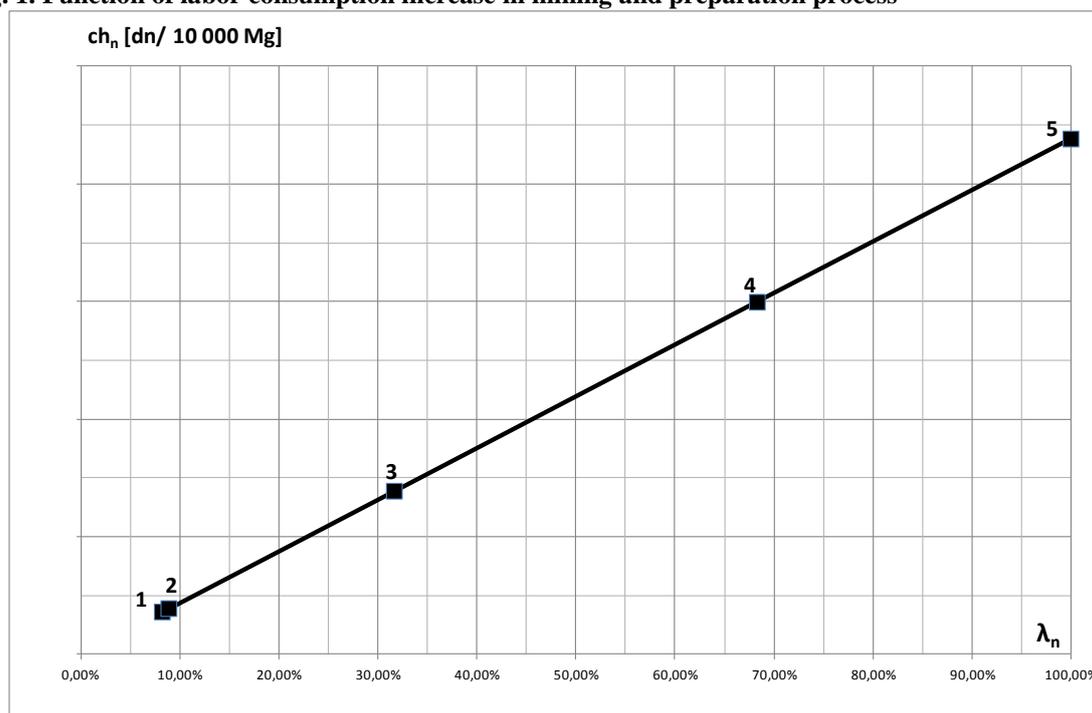
The relation between the labor consumption of a given stand ( $ch_n$ ) to the labor consumption of the mine as a whole ( $ch_{kop}$ ) (general relationship 2) by index  $\lambda$  is given by:

$$ch_n = \frac{\lambda_n}{100} \cdot ch_{kop}, \quad (10)$$

$$ch_{kop} = \frac{100}{\lambda_n} \cdot ch_n, \quad (11)$$

The above relationships are illustrated by the graph of labor consumption growth in fig. 1.

**Fig. 1. Function of labor consumption increase in mining and preparation process**



Key: 1- work in the deposit, 2 – work at the face, 3- work in the field, 4 – work underground, 5- work in mine

From the author's resources.

After the substitution of labor consumptions indexes with work efficiency indexes (general relationship 1) :

$$w_n = \frac{100}{\lambda_n} \cdot w_{kop}, \quad (12)$$

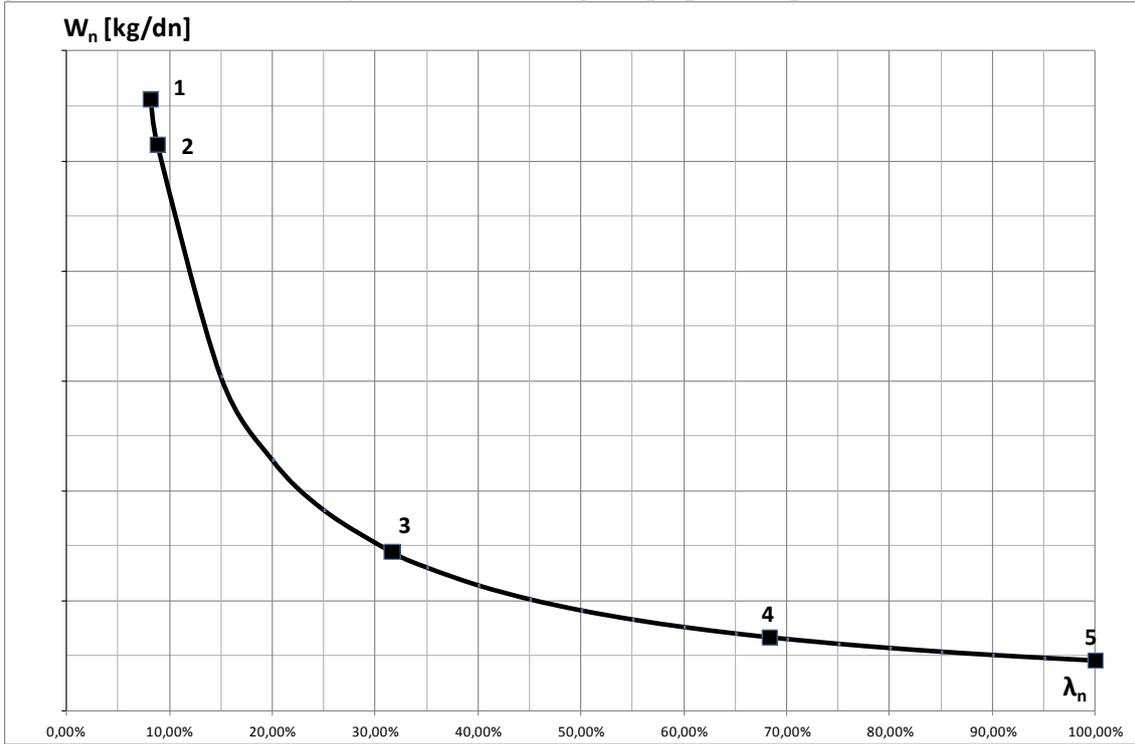
$$w_{kop} = \frac{\lambda_n}{100} \cdot w_n, \quad (13)$$

A graphic presentation of the above relations is given by the line of efficiency decrease in figure 2.

Zidentyfikowaną za pomocą wskaźników  $\lambda$  krzywą spadku wydajności w warunkach analizowanej kopalni charakteryzuje ponadto zestaw wskaźników redukcji wydajności  $\eta_n$ .

The line of efficiency decrease in the conditions of the mine under investigation, which is identified by indexes  $\lambda$ , is also given by a set of efficiency reduction indexes  $\eta_n$ .

**Fig.2. Function of work efficiency decrease in mining and preparation process**



Key: 1- work in the deposit, 2 – work at the face, 3- work in the field, 4 – work underground, 5- work in mine

From author's resources.

When analyzing the efficiency decrease with the consideration of the efficiency

- in the deposit -  $w_w$ ,
- at the face -  $w_p$ ,
- in the field -  $w_g$ ,
- underground -  $w_d$ ,
- general -  $w_{or}$  and  $w_{op}$

the efficiency reduction indexes  $\eta_n$  are given by :

$$\eta_1 = \frac{w_p}{w_w} \quad (14)$$

$$\eta_2 = \frac{w_g}{w_p} \quad (15)$$

$$\eta_3 = \frac{w_d}{w_g} \quad (16)$$

$$\eta_4 = \frac{w_{or}}{w_d} \quad (17)$$

$$\eta_5 = \frac{w_{op}}{w_{or}} \quad (18)$$

The efficiency reduction indexes  $\eta_n$  make it possible to identify directly the most labor consuming areas of the production process and the analysis based on them facilitates a determination of the adequate direction of technical and organizational operations. The possibility to apply the efficiency reduction indexes to assess the results of the operations is also worth mentioning

### 3. Work efficiency measures in mining

At present the following quantitative measures of work efficiency are commonly used in hard coal mining:

1) *Yield  $w_d$ , determined by*

$$w_d = \frac{U_w}{D_d} \text{ [kg/workdays]} \quad (19),$$

where:

$U_w$  - coal yield, gained underground and transported to the surface [kg],

$D_d$  - number of workdays underground.

2) *General efficiency of the work in the deposit, determined by:*

$$w_{or} = \frac{U_w}{D_r} \text{ [kg/workdays]}, \quad (20)$$

where:

$U_w$  - coal yield, gained underground and transported to the surface,

$D_r$  - total number of workdays of the production sector staff (excluding the preparation plant).

3) *General efficiency in commercial coal wop determined by:*

$$w_{op} = \frac{U_h}{D_p} \text{ [t/taff workdays]}, \quad (21)$$

where:

$U_h$  - number of tons of commercial coal (net output),

$D_p$  - number of workdays of the production sector staff.

Additionally, for the requirements of the work efficiency analysis in hard coal mining, the adequate numbers of workdays (or staff workdays) related to the gross output  $U_w$  make it possible to determine and apply the following indexes:

- Efficiency in the deposit –  $w_w$ ,
- Efficiency at the face  $w_p$ ,
- Efficiency in the field –  $w_g$ .

In ore mining work efficiency indexes relate to 1 workday and there are:

- face efficiency [kg/workday],
- field efficiency [kg/workday],
- underground efficiency [kg/workday],
- general efficiency [kg/workday].

and general efficiency per one staff workday [kg/staff workday]

Moreover, in comparative analyses work efficiency indexes are determined in relation to:

- one employee and the number of tons of commercial coal,
- amount of total ore mined and the amount of copper in the ore,
- one underground worker, the amount of individual output and the amount of copper in the individual output [kg/one employee].

Thus, in general sense the efficiency indexes in mining are determined in relation to the subsequent stages of the mining and preparation process, which enables the identification of the line of efficiency decrease in the process by determining :

- the efficiency in the deposit (coal, ore or rock),
- the face efficiency,
- the efficiency in the field, related to the mining or preparation faces,
- the underground efficiency,
- the general efficiency.

The work efficiency indexes can also be analyzed in relation to the selected groups of stands or operations, such as:

- mining faces,
- preparation faces,
- out of face operations,
- horizontal transport,
- vertical transport,
- surface operations,
- preparation plant.

### 3. Efficiency decrease function and the basic areas of analysis

The efficiency analysis of the mining and preparation process can be conducted by different approaches<sup>2</sup>:

- the efficiency decrease line can be analyzed as regards the possibility to reveal the direction of the desired restructuring operations through the identification of stands (or operations) in the mine or group of mines that cause a significant efficiency reduction;
- the dynamics of change in work efficiency can be investigated in relation to the whole mine and particular groups of operations from the point of view of the quality and effectiveness of the undertaken restructuring operations;
- a comparative analysis can be conducted of the efficiency of the same stands (or groups of operations) in mines, that are comparable when natural conditions are concerned but different when considering the technologies (technological and organizational systems, mine models) applied, with the aim to assess the usefulness of particular solutions to given conditions.

The investigation of work efficiency can be carried out with the application of absolute or relative deviations. Absolute deviations make it possible to analyze the changes in work efficiency levels in relation to one or more mines:

- in the case of the same group of stands it is possible to determine the change trend as a positive or negative one,
- in the case of different operations at the same time it is possible to identify the least efficient stages of the production process under investigation.

Relative deviations make possible the percentage analysis work efficiency level changes in one or more companies in statistical approach (the comparison of efficiency reduction indexes in a given period of time for subsequent production process stages) or dynamic

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<sup>2</sup> K. Baluch, *Wykorzystanie wskaźnika pracochłonności w analizie efektywności pracy ludzkiej*, „Wiadomości Górnicze” 1999, No 1.

W. Krawczyk., B. Jabłońska-Firek, *Ekonomia przedsiębiorstwa górniczego*, Skrypty uczelniane AGH w Krakowie, Kraków 1980, No 702.

D. Matys, *Wpływ zmian restrukturyzacyjnych na wydajność i poziom zatrudnienia w wybranej kopalni*, praca magisterska – WGiG AGH w Krakowie, Kraków 1997.

A. Satuła, *Analiza struktury zatrudnienia i krzywej zmian wydajności w wybranym zakładzie górniczym*, praca magisterska – WGiG AGH w Krakowie, Kraków 2001.

A. Utrata, *Wykorzystanie funkcji narastania pracochłonności do analizy chłonności pracy procesu wydobywczego-przerobczego*, „Przegląd Górniczy” 2011, vol. 67, No 9.

approach (the comparison of indexes from different periods of time). The efficiency decrease line (called the Krupiński curve) is a function where work efficiencies  $w_n$  (12) for subsequent stands (or operations) is the dependent variable, while variable  $\lambda_n$  (9) is the argument of the function, and determines the ratio of workdays  $D_n$  in a group of stands (or operations) to the total number of workdays  $D_{kop}$  for the mining and preparation process under analysis. Work efficiency decrease functions can be presented analytically or graphically. In the analytical version, the arguments of the function and its values are given in a table, which makes it possible to analyze the mining and preparation process as regards the structure of labor consumption illustrated by indexes  $\lambda_n$  and the decreasing efficiency level that results from the realization of subsequent stages of the production process. The graphical version of the efficiency decrease function enables a similar analysis. An example of the tabular and graphical presentation of the function is given in table 1 and figure 3. The arguments and values of work efficiency decrease function are illustrated by columns 5 and 6 in table 1 and figure 3. Columns 3 and 4 illustrate indirectly the coordinates of points 1,2, 3, 4, 5, 6 . Column 7 in table 1, illustrating the reduction efficiency indexes, points directly at the areas responsible for the most significant efficiency decrease; hence, it gives outlines regarding the direction of adequate restructuring operations. The efficiency decrease line, exemplified by table 1, fig.3 , which is a statistical approach to the efficiency decrease issue in the mining and preparation process, does not allow for the determination of trends as regards the changes of efficiency levels in particular stages of the process under analysis.

The investigations of the dynamics of work efficiency changes in particular stages (in relation to selected groups of operations) or in relation to the whole production process require the knowledge of efficiency decrease lines in different periods of time. A comparative analysis that was conducted on their basis enables the determination of the character of the trends and the assessment of the effectiveness of the undertaken restructuring operations

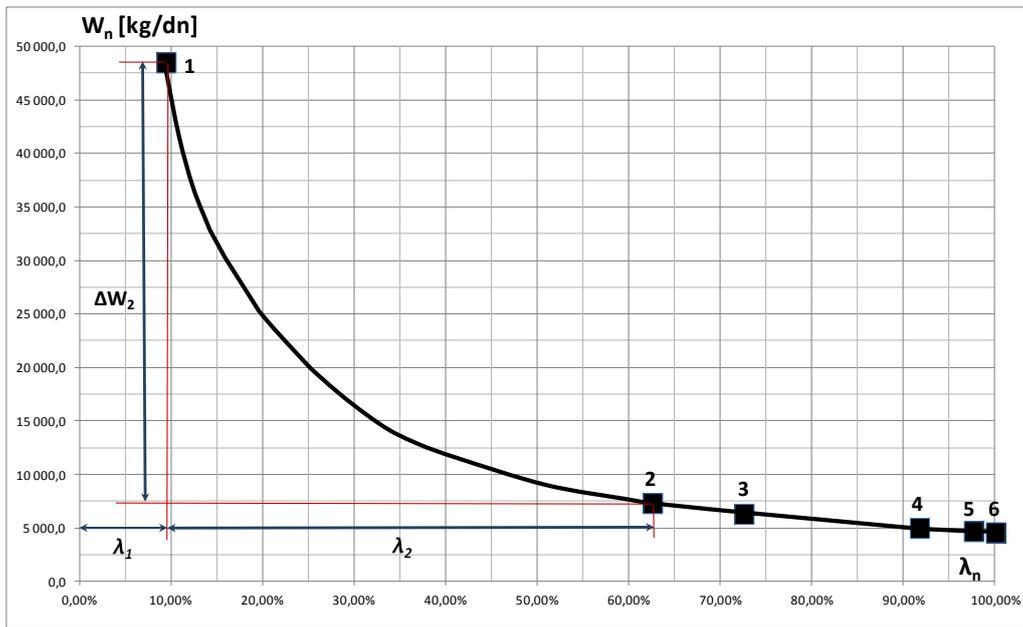
**Table 1. Characteristics of work efficiency for a selected mining and preparation process**

No	Operations (stands)		No of workdays – group $D_n$	Ratio of workdays of the group to total number of workdays $\lambda_n$	Ratio of workdays, increasingly	Efficiency of the group of operations $w_n$ [kg/day]	Efficiency decrease in groups of operations $\Delta w_n$ [kg/day]
	Name	$n$					
	1	2	3	4	5	6	7
1.	Face	1	5 940,00	9,41%	9,41%	48 487,9	0,0
2.	Out of face	2	33 529,00	53,14%	62,55%	7 297,3	41 190,6
3.	Underground supervision	3	6 302,00	9,99%	72,54%	6 292,6	1 000,7

4.	Workers on the surface	4	12 092,00	19,16%	91,70%	4 977,6	1 315,0
5.	Supervision on the surface	5	3 718,00	5,89%	97,59%	4 677,1	300,5
6.	Administration and engineering	6	1 518,00	2,41%	100,00%	4 564,5	112,5
7.	Total – mine	7	63 099,00	100,00%	100,00%	4 564,5	–

From author's investigations, based on data from a selected mine .

**Fig 3. Work efficiency decrease function for a selected mine**

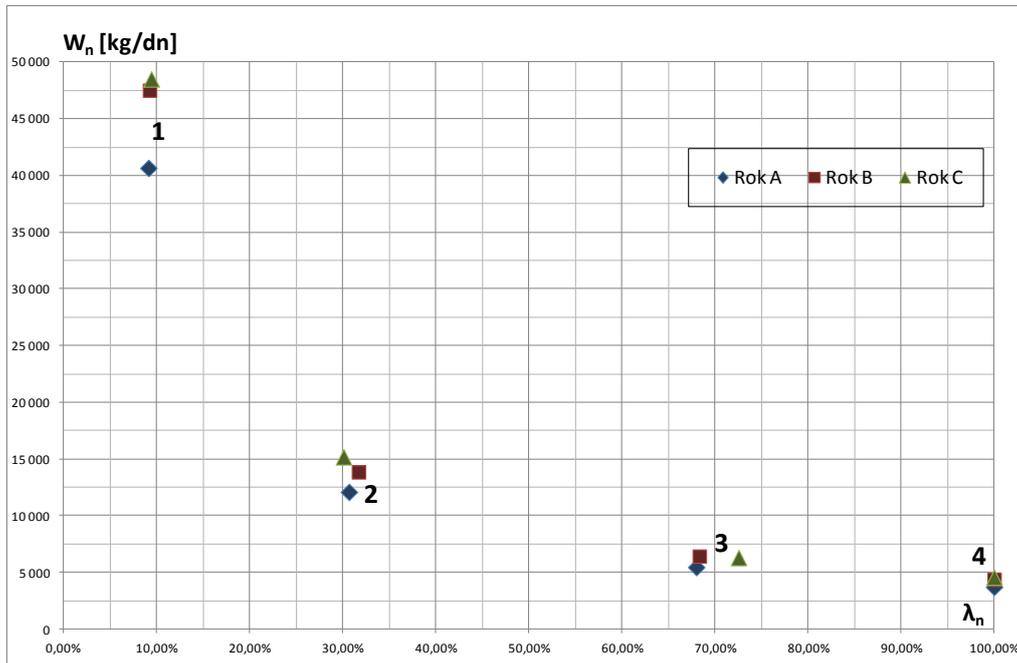


Key: 1 – face operations, 2 – underground operations without supervision, 3 – underground operations with supervision, 4 – underground operations + workers on the surface, 5- mine without office, engineering and technical staff, 6 - mine

From author's investigations, based on data from tab.1.

The examples of efficiency decrease functions for three subsequent stages are illustrated by fig.4, where it is visible that the increase of face efficiency was reduced practically to zero as a result of the increase of the labor consumption in out of face, underground and surface operations.

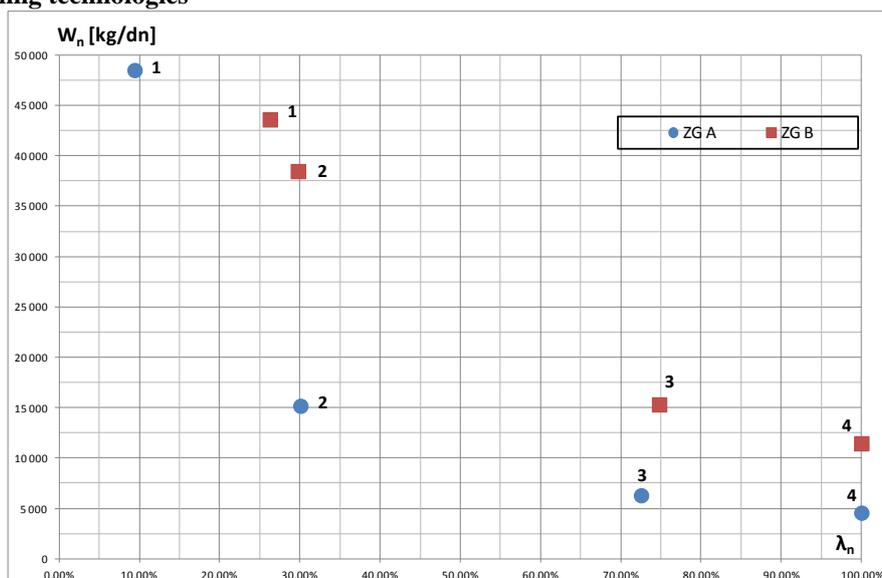
**Fig.4. Functions of work efficiency decrease in a selected mine – a dynamic approach**



Key: 1 – face efficiency, 2 – field efficiency, 3 – underground efficiency, 4 – general efficiency  
From author's investigations based on data from a selected mine.

Fig.5 presents two functions of work efficiency decrease for two different mines, calculated on the basis of four selected groups of operations.

**Fig.5. Work efficiency decrease functions for two selected underground mines with different resource areas and mining technologies**



Key: 1 – face efficiency, 2 – field efficiency, 3 – underground efficiency, 4 - general efficiency  
From author's investigations, based on the data from the selected mines

On the basis of figure 5, significant differences can be observed in the efficiency levels of the mining and preparation processes under investigation. There are also substantial differences in work efficiency levels as regards particular groups of operations. However, it is interesting to see that the percentage share of field and underground workdays in both cases is nearly identical.

## Conclusion

The characteristics and possibilities of using work efficiency decrease functions to analyze mining and preparation process was presented against the background of the characteristic features of production processes and the conditions for their effective realization in mining. The following general conclusion can be drawn on the basis of the performed analysis:

- The knowledge of the work efficiency decrease function as regards the mining and preparation process in a particular mine enables a quick analysis of work efficiency with the relation both to the whole process and its elements. The analysis can indicate the desired direction of restructuring operations.
- A comparative analysis of the efficiency decrease functions for different stages makes it possible to assess the restructuring operations as regards their impact on the effectiveness of a particular stage or the whole production process.
- The comparison of work efficiency decrease functions calculated for different mines should help identify the reasons for the differentiation of work efficiency levels in the processes under investigation or in their selected elements and – as a result – it may constitute the basis for a better adjustment of technical and organizational solutions to the natural geological and mining conditions in mines.

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### ***Summary***

Considering the terms of work efficiency and labour consumption as well as the specificity of the production processes in coal mining, the function of work efficiency decrease was characterized. Also the needs and possibilities of its examination and analysis in the aspect of monitoring and controlling mining and processing were presented. The needs and possibilities were illustrated by examples, which described functions of work efficiency decrease in the static and dynamic approach with reference to selected mines.