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The simulation of longwall complex mechanized operating face system

Introduction

The analysis of the production process and use of some instruments for prospecting – organization also tried to develop models in order to help taking decisions and develop the optimal mining production organization (based on mathematical calculations) or as close as possible to that (based on approximations which takes into account production restrictions).

For projecting the organization of simple processes it's needed to be established certain objectives or purposes which have to be transformed into optimizing criteria of organizing solutions. Starting from objective relations between simple process parameters and also between the elements of the production process (people, machines, geological – mining characteristics), it's required an analysis of the decision variables influence over the optimizing criteria in certain conditions and respecting some restrictions caused by the geological, mining, technical, organizing and security characteristics. Such analysis can be done only through certain models given by quality structural and quantity relations under mathematical form.

The most important characteristic of the modeling method is the possibility to find solutions to complex production organizing problems which are almost impossible to be solved otherwise. Often, the improvements of an influential factor may cause drawbacks to other factors.

Modeling determines the rational domain for applying different forms of production organization and establishes the optimal parameters of each organization form in different geological-mining conditions.

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1. The analysis of the production factors of basic mining process using the production economical theory

The extraction process of a coal deposit from a coal face field in a mining exploitation, can be considered the production process, being characterized by combining and transforming economic resources, for obtaining goods with economical value, using transforming and combining methods, routines and relations implemented and lead by people.

The used resources in the process are called *production factors*, meaning that they are active resources – economic goods used for their productive potential – production factors used through precise economic decision. Following the path the transforming and combining relations of the process will be called *production functions*, defining the connection between the production factor actions and the result of the process, called *output.*

Observing the characteristics of the production system we notice there the characteristics of a production function: productive resources are used (capital, human work, materials, energy) combined after a method imposed by managerial decisions and technological restrictions, oriented towards obtaining the output (green coal) and correlated by mathematical transformation relations inside a mining production system.

The specific mining production factors and their use conditions are different compared to the preparation industry. However, there are some similar functions like the substitution of the production factors (limited by the technology).

The factor use levels present discrete variance, not continuous. For example the raise of the human work use level is done by raising the number of workers of a face work unit; similar discrete variances can be met for other input factors.

Also, we can determine some important parameters of rationalizing the mining process like time adapting and relocation of work and/or mining technique factors from some activities that can be paused towards others that need to be accelerated.

From describing different function types, like Kloock treats human work as potential factor, it results the connection between the human work factor and the mining technique, both technologically and also through the qualification of the work units that use the technique.

The basic processes of coal underground exploitation correspond to the production theory criteria. They imply factor consumption and end with obtaining an output element, the coal mining product, after the exploitation process.

The basic processes needed to realize the coal production work by combining the effect of the production installations factor (a specialized machine or group of machines) with the human work factor (a group of workers with different qualifications in the work face, that use, support and control the installations). An important observation is that the two factors combine into a technological unit, and cannot work separate.

Because the most important factors used in a work face are the potential factors, especially human work and production installations, we will focus on describing these two factors, especially the human work because it influences the use of the production installations. We can say that by planning the human work we also plan the use of the machines.

2. Types of mathematical modeling for simple face work process

For establishing the mathematical relations between the optimizing criteria and technical-mining, technological and organizational parameters there were proposed multiple modeling types of the simple process, most of them reflecting the main structural relations of the production cycle.

1. *The model based on separating the technological stages of the process in repeatable and non-repeatable*

The simple process is divided into repeatable and non-repeatable complex operations, each of these also divided into repeatable and non-repeatable operations.

The mathematical relations are established at the level of complex operations or simple process. Theoretical studies spotted the way to influence certain parameters in order to obtain the desired results.

For optimizing the organization of the simple process it is determined the work level for every worker among the total work level of each complex operation.

2. *The model based on the relation between the cutting installation functions and the manual works from the front on mechanized longwall faces*

On longwall mechanized cutting faces, beside organizing in time the simple process, another problem is the space organization that means establishing the front parts and the people who will execute the complex operations of the production cycle there.

The relation between the machine functions on the face and manual work execution generates an organizing problem that was called matching the manual works on the front with machine functions. After solving the problem it results the number of men that will be distributed on the front and the length of front parts where each of them will execute the manual works during the production cycle.

Compared with the variable *n* (number of workers on each front) there were analyzed three functions – objectives – that can be viewed as optimizing criteria: length of the cycle, work efficiency of the whole work unit on the face (including auxiliary and management) and costs on extracted layer. If we know the length of the production cycle as a function on the number of men on the front, that execute the manual works, we can determine the two other functions and also the shift or daily production function.

The mathematical programming model released to solve the problem doesn't take into consideration the works at the edges of the face (staples and intersections) considering that they can be organized independently, by a work unit with this purpose, depending on how the front advances and the length of the cycle. Also, the model considers that the shearer stops, caused by manual work delays, appear only during cutting works. When the face conditions generate shearer stops due to manual work delays or by machine maintenance or repositioning, the model is completed with restrictions as for cutting works.

3. *The model based on splitting the mechanized cycle in longwall faces in two phases and the manual works on the face in three categories*

Compared with the previous model there are the following conditions:

- the shearer with constant cutting speed v_1 and maintenance (and repositioning) speed v_2 will have at the edge of the face two mandatory stop periods a_1 – before the cutting works and b_1 – before the maintenance / repositioning works, periods that have standardized fixed values for any face;
- the people start working with the delay d_1 after the shearer cutting works and with the delay d_2 after the maintenance works (delays given by work security standards);
- the people work places on the front are unknown;
- the manual works on the work face part in three groups (works that start after the shearer cutting works, after the d_1 delay and end before the start of the shearer maintenance / repositioning works; works that start after the shearer maintenance / repositioning works, after the d_2 delay and will end before starting a new cutting work; works on the face that can be executed in the same time with the previous ones and are independent on the shearer position on the front).

This model also wants to find the cycle length as a function on the number of workers, which need to have maximum daily production and maximum work productivity. There are cases when the two criteria cannot be simultaneously fulfilled and it is needed to apply the minimum expenses criteria function on the number of workers and cycle length.

4. The model based on equalizing the shearer speed with the manual works rhythm

For process modeling in mechanized faces there were a lot of contributions regarding functions on cycle length and number of workers. The shearer cycle was described with an alternation of cutting and stop periods. The idea of splitting the cycle in two phases (cutting and maintenance) was kept and standardized stops at the edge of the face (a_1 and b_1) were admitted.

In the model there were introduced the stops or delays of the shearer caused by manual work delays and the stops that have other causes than manual work delays.

Depending on the difference between n_3 (available workers on the front in the second phase of the cycle after a flitting team was formed) and n'_3 (workers needed on the front for executing the second phase manual works with the same rhythm as the maintenance speed) and on the difference between n (total number of workers) and $(n_1 + n_2)$ (n_1 – the flitting team that follows the shearer; n_2 – number of workers on the front) – we can have two cases: either the cycle will have a minimum period and an incomplete use of the work fund so the productivity won't be maximized or the cycle will have a longer period due to delays and the productivity will be maximized. We can establish relations for the shearer waiting periods and for work units stop periods depending on the speeds v_1 and v_2, on the manual works volume m_1 (standardized works for manual operations on the front for the first team that follows the shearer n_1 workers, worker-minute/meters) and $k.m_2$ (m_2 – standardized works for manual operations on the front for the second team that follows the shearer n_2 workers, worker-minute/meters; $k \in [0,1]$ – correction coefficient of the number of workers n_2 between faces or shifts depending on the face conditions) and on the number of workers n_f from the units that follow the shearer ($n_f = n_1 + n_2$).

3. The model based on admitting the random character of interruptions for shearer face works

The presented models either didn't admit stops due to non-management causes, either admitted them but didn't affect the management solution. The model that will be presented below gives a solution that will admit the shearer stops which will cause manual work stops.

The simple hypothesis from the above presented models considered that the shearer front advance speed are uniform, independent on the front conditions or neglected the possibility that shearer works will stop when it will reach certain points on the front line. The interruptions have technical causes, technological, geological-mining and organizational, and can appear inside or outside the face perimeter. When the shearer presents an interruption, the work teams that follow the shearer with manual works are in the situation to not have work front so they cannot use their work time productively until the shearer works start again. In a situation that admits that the shearer work interruptions are unavoidable, the problem will be to find the causes of these interruptions and to adapt the number of workers on the front and their distribution to unexecuted works when an interruption appears.

In order to solution the face work management problem, admitting a random stop of the shearer work, there were done researches for finding the probabilities for advance speed and for interruptions. It is admitted that a face work cycle consists in an alternation of *k* periods when the shearer advances or it is stopped, like in Figure 1.

Each *k* period with length t_k needs to have a certain number of workers on each *i* complex operations, that form the problem unknowns x_{ik}.

A shearer cycle is simulated based on the probability laws established for:

1. *The shearer advance speed*, standard repartition law on the probability density function with form:

$$f(v_1) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(v_1-\mu)^2}{2\sigma}} \tag{1}$$

where:

v_1 – shearer cutting advance speed (variable),
μ – normal repartition law mean, $\mu \approx \bar{v}_1$,
$\bar{v}_1$ – mean advance speed determined on face work conditions,
σ – mean square deviation of the normal repartition law, $\sigma \approx s$;
s – mean square deviation of the advance speed correspondent to the mean speed $\bar{v}_1$.

2. *The length of the interruption periods caused by technical problems*, inside or outside the face perimeter, gamma (Γ) repartition law on the probability density function with form:

$$f(t) = \frac{\lambda^{\eta}}{\Gamma(\eta)} t^{(\eta-1)} e^{-\lambda t} \tag{2}$$

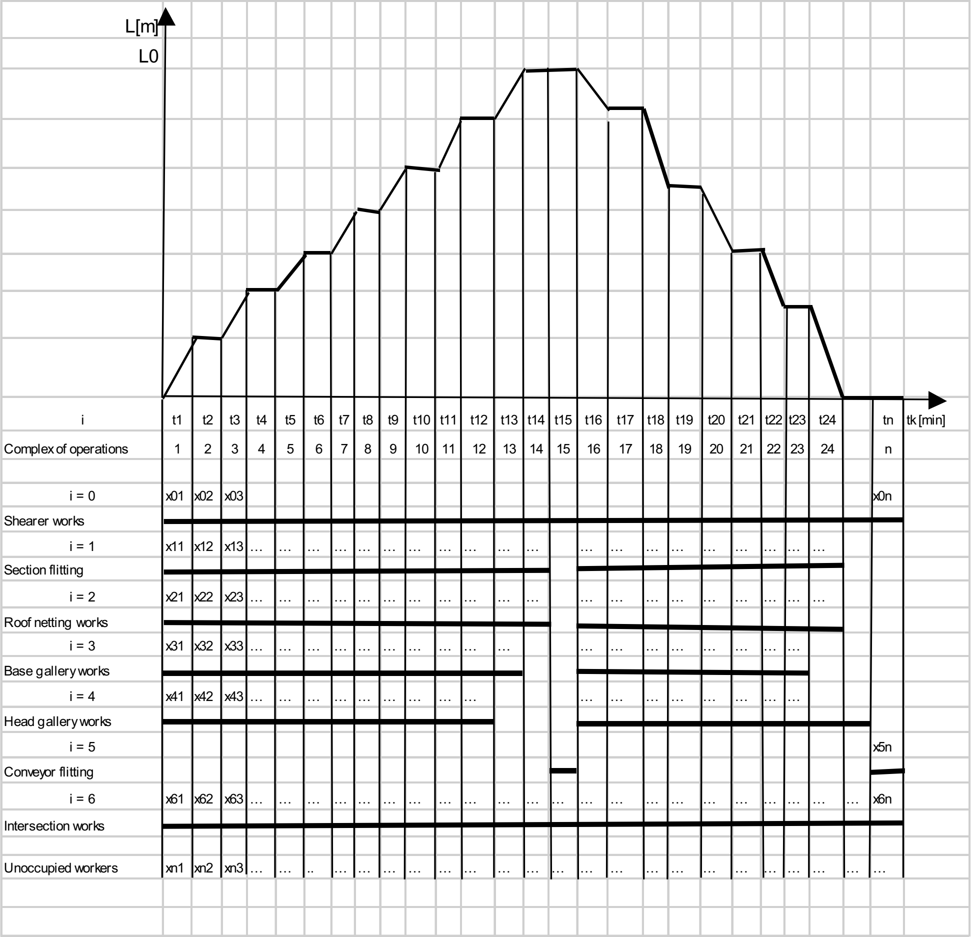

Fig. 1. Face work cycle model

Rys. 1. Model cyklu pracy w przodku

where:

λ, η – parameters of the gamma (Γ) probability law,

$\Gamma(\eta)$ – gamma probability function.

For determining the parameters λ and η of the repartition law the face works are monitored and the data are processed using mathematical statistics.

3. *The length of interruptions caused by face work management*, exponential repartition law on the probability density function with form:

$$f(t) = \lambda e^{-\lambda t} \tag{3}$$

4. *The length of interruptions caused by geological-mining issues,* exponential law same as point 3.

5. *The probability of any kind of interruption appearance*, Poisson repartition law on the probability density function with form:

$$P(m)=\frac{\lambda^m}{m!}e^{-\lambda} \tag{4}$$

where:

λ – mean frequency of interruption appearance for each 100 meters of front cut by shearer,

m – number of interruption appearances for the front length l.

For every simulated cycle we get a mathematical programming model that presents the following restrictions:

a) enclosing the work fund for each complex operations i ($i=\overline{1,m}$) for every period k ($k=\overline{1,n}$) into the standardized work consumption of the complex operation i, is defined by the relation:

$$\sum_k t_k x_{ik}+\sum_k \tau_{ik}(z-b_i)=M_i,(i=\overline{1,m}) \tag{5}$$

b) the use of a constant number of workers for every period k equal with the number of workers per shift of the face:

$$\sum_k x_{ik}+x_{nk}=z,(k=\overline{1,n}) \tag{6}$$

c) respecting an admitted delay between every pair of complex operations i_1 and i_2:

$$\sum_k N_{i_1}x_{i_1k}t_k+\sum_k N_{i_1}(z-b_{i_1})\tau_{i_1k}-\sum_k N_{i_2}x_{i_2k}t_k-\sum N_{i_2}(z-b_{i_2})\tau_{i_2k}\ge d_{i_1i_2} \tag{7}$$

d) limiting the number of workers for every period k and each complex operation with the maximum number of workers admitted on the given work face:

$$x_{ik}\le x_i^{\max},(i=\overline{1,m}),(k=\overline{1,n}) \tag{8}$$

e) realizing the daily planned production:

$$\frac{T_z}{t}Q_c\ge Q_z \tag{9}$$

where:

i – complex operation index,
m – number of complex operations for the simple process,
k – cycle work period index,
n – cycle number of periods (shearer works and stops),
t_k – length of the k period of shearer work or stop,
M_i – workload determined on the standards for the i complex operation,
τ_{ik} – length of the periods necessary for recovering the delays of the complex operations compared with shearer works, due to the differences between execution speeds,
$t = \sum_k t_k + \sum_i \sum_k \tau_{ik}$ – length of the face work cycle,
T_z – daily productive time,
z – number of workers in the team per shift,
x_{ik} – number of workers in the unit that execute the i complex operations in the period with length t_k,
x_{nk} – number of unoccupied workers in the period with length t_k,
$x_i^{\max}$ – maximum number of workers that can be used to execute the i complex operations,
b_i – number of workers that cannot be used to recover the delays after the i complex operations,
$d_{i_1} d_{i_2}$ – the admitted distance (on the front line) between the execution spots of the operations i_1 and i_2,
$N_{i_1} N_{i_2}$ – standard productivity of a worker on complex operations that present delays (opposite of the work consumption per front meter),
Q_c – coal production per cycle,
Q_z – daily planned coal production.

The mathematical model has as objective the work productivity of its opposite – the work consumption for 1000 tons expressed in workers-shift given by the relation:

$$\min\{x_0\} = \frac{t(z+n_a)1000}{T_z Q_c} \tag{10}$$

where:

n_a – represents the number of workers per shift with the following roles: serve, supply, transport control, face management (for each technological unit).

An analysis of the model shows that it takes into consideration all the aspects from previous models and brings the following additions:

— enclosing the work consumption in the work fond at shift level for every complex operation, with relations (5) and (6). This enclosure is not used in the model 1, while models 2, 3 and 4 from the presented previously admit a number of workers that do not use entirely their work hours;

- admission of delays between complex operations that need to be executed with a correlated rhythm, like model 4, with relation (7);
- admission of interruptions for shearer works, caused either by face work management or by recovering different delays, with relations (5) and (7);
- introduction of maximum number of workers for complex operations, with relation (8);
- introduction of reorganization rules for front work units in interruption periods (caused by delays or other problems).

Having a probabilistic approach of the problem and introducing extra restrictions, the model gets closer to the reality compared with previous models. Its application is conditioned by research for obtaining the parameters of the probability laws, by having an adequate software for data processing and statistic calculations and by the qualification of the personal that will use the model and interpret the data.

In order to simplify the problem of obtaining the solution, the model was adjusted with reducing the configuration of the cycle from n periods of t_k length obtained by simulation to a number of a few *cycle phases*.

The face phase is the period of time when the worker repartition for complex operations remains unchanged. A phase time length is the mean value of the simulated cycles based on the probability laws specific to the face. The model of the face cycle when random periods t_k are replaced by phases is shown in Figure 2.

For getting the mathematical model based on phases and not on t_k timings we use the following expressions:

z^* – number of workers on the front line (on the shearer, flitting and other works on the front),

T_1 – shearer work time,

T_{01} – shearer stop times with length less than 10 minutes,

T_{02} – shearer stop times with length over 10 minutes but less than 20 minutes when the shearer is situated less than 30–40 meters away to the destination gallery,

T_{03} – shearer stop times with length over 20 minutes when the shearer is situated less than 30–40 meters away to the destination gallery.

With this convention regarding interruption times we get the rules for reorganizing the work units on the front:

- for interruptions with length over 10 minutes and shearer situated over 30–40 meters to the destination gallery, the front workers (on the shearer or following it) get reorganized to execute the manual works on the front, without going to the intersection of the face with the galleries;
- for interruptions with length over 20 minutes and shearer situated less than 30–40 meters from the destination gallery, work units get reorganized taking into consideration sending workers to the galleries.

Complex operations		Cycle phases																	
		Normal															Delay recovery		
		Shearer preparation	Conveyor flitting	Shearer cutting	Stops			Delay recovery	Shearer preparation	Conveyor flitting	Shearer cutting	Stops			Delay recovery	Section flitting	Front leveling	Head gallery intersection	Base gallery intersection
					T_{01}	T_{02}	T_{03}					T_{01}	T_{02}	T_{03}					
		1	2	3	4	5	6	7	1	2	3	4	5	6	7	8	a	b	c
i = 0	Shearer works	x_{01}	x_{01}	x_{01}	x_{01}	x_{05}	x_{05}		x_{01}	x_{01}	x_{01}	x_{01}	x_{05}	X_{05}		x_{08}	x_{08}	x_{01}	x_{01}
i = 1	Section flitting			x_{13}	x_{13}	x_{15}	x_{16}				x_{13}	x_{13}	x_{15}	x_{17}		$z^*=b_1$			
i = 2	Roof metal netting works																		
i = 3	Head gallery intersection works	x_{31}	x_{31}	x_{31}	x_{31}	x_{31}	x_{31}		x_{31}	x_{31}	x_{31}	x_{31}	x_{31}	x_{31}		x_{31}	x_{31}	x_{31}	x_{31}
i = 4	Base gallery intersection works	x_{41}	x_{41}	x_{41}	x_{41}	x_{41}	x_{41}		x_{41}	x_{41}	x_{41}	x_{41}	x_{41}	x_{61}		x_{41}	x_{41}	x_{41}	x_{41}
i = 5	Conveyor flitting		x_{52}							x_{52}									
x_{nf}	Unoccupied workers	x_{n1}	x_{n2}	x_{n3}	x_{n4}	x_{n5}	x_{n6}		x_{n7}	x_{n2}	x_{n3}	x_{n4}	x_{n5}	x_{n8}		x_{n9}	x_{n10}	x_{n11}	x_{n12}

Fig. 2. Face cycle phases

Rys. 2. Fazy cyklu w przodku

For each face we calculate the mean time lengths of the phases, considering the probability laws the apparition lengths and frequencies of the three categories of interruptions and the advance mean speed $\overline{v}_1$.

4. The geological-mining characteristics and the principal parameters of a technological production unit

The technological production unit analyzed is the front face situated on layer 3, board 2C, block IV from the perimeter of Lupeni Mining Exploitation.

Layer 3 of block IV presents 6–14° mean declivity and 27 meters gauge. In this block the coal deposit is exploited using the bulk layer exploitation method through undermining behind the front line or using the bulk layer exploitation method through horizontal slices, in frontal faces with mechanized support and cutting.

The mining work observations revealed the physical-mechanical and elastic characteristics of layer 3:

- specific density, γ_a – $1.43 \cdot 10^4$ N/m^3,
- one-axis compression break resistance, σ_{rc} – 8–18 MPa,
- traction break resistance, σ_{rt} – 4.6 MPa,
- cohesion, C – 1.8 MPa,
- interior friction angle, φ – 40°,
- elasticity module, E – 548 MPa,
- Poisson coefficient, μ – 0.20,
- coal dislocation angle, β – 74°,

— natural slope angle, ϕ – 62°,
— decline angle, ω – 132°.

The coal deposit is self-flammable with high self-ignite character. Therefore, the extraction needs to as few as possible coal losses in order to prevent endogenous fire.

On board 2C, the length of the direction panel is 240 meters, the coal exploitation takes place under natural roof and the face front length is 100 meters.

The face is equipped with machines made in Poland:
— mechanized support type TAGOR – 18/37 – POz/P;
— face shearer type KSW-460NE Ǿ1800X800;
— conveyor type TAGOR 260/750 h=3.

The electrical advance shearer, type KSW-460NE has two arms that work on the face front mine conveyor in a system without traction bar type Eicotrack.

It is destined for extracting from two directions and for loading the extracted material from the mining faces with transversal declivity up to 25° up and up to 20° down and with longitudinal declivity up to 35°. For these declivities the shearer corresponds to the stability conditions, both during stops and works.

Presenting very good technical parameters the shearer works on high efficiency parameters. It is compact constructed, self-supporting shearer.

The shearer advance is operated through two action assemblies, each of them being powered by an asynchronous three-phase engine. Engines are powered by the power freququency converter provided by the shearer.

The maximum capacity of the shearer is given by the maximum speed (0–20 meters / minute), cutting height (3.7 meters), drum width (0.8 meters) and coal volume weight (1.6 t/m^3), the value being 95 tons / minute at maximum speed.

5. Production simple process organizing simulation from longwall faces

For computer simulation it is utilized a mathematical model that describes the behavior of the real system (longwall face) over a time period equal with the face production cycle.

To simulate the activities from longwall faces there were used procedures to generate different types of random variables, while for practical model building it was elaborated a program that uses the toolbox of the program MATLAB.

The mathematical simulation model presents two important classes of elements: *input* and *output* elements, each class containing variables and parameters.

The simulation model presents also *functional relations (identities* and/or *equations)* and operative characteristics used to express, through mathematical relations, the variable interactions and system functioning.

An *operative characteristic* is the expressed statistical hypothesis that connects the system input variables. Because these variables are stochastic, the operative characteristics have the form of a density probability function, in this case, among the input parameters of the model we will find also the statistical parameters of the operative characteristics. In the simulation model the parameters have the role of input data and were estimated by statistical observations of the technological process for the longwall face system that was simulated.

After building the simulation model, the simulation itself, as an experiment, consists in alternating the system characteristics (variable and input parameters values) and deducting by the model, as calculation results, their effects over the others characteristics of the process (output variables).

1. *Organizational simulation model projecting basics*. The face process that deems the organization project has the purpose of extracting slices of black coal using the shearer and supported by mechanized installations. Data regarding geological-mining conditions, physical-mechanical rock and coal properties and technical, technological and organizational data are found in Table 1.
2. *Face process analysis*. In Table 2 we have a brief description of the analysis used for process modeling. All the complex operations on the front and face intersection with the galleries were grouped, forming three groups of works used to determine the work consumption per cycle that implies cutting a slice. Standard, work load and work consumption calculations were made after the methodology applied in mining industry.

TABLE 1

Input data for organizational projecting

TABELA 1

Dane wejściowe dla projektowania organizacji

No.	Specification	Symbol	Value (description)
1	Layer declivity	α	10°
2	Coal cutting resistance		8–18 Mpa
3	Coal structure		compact
4	Floor rocks		coal
5	Roof rocks		sandstone
6	Conveyor type		TAGOR 260/750; h = 3
7	Shearer type		KSW-460NE Ø1800X800
8	Mechanized support type		TAGOR-18/37-POz/P
9	Volume weight	γ	1.43 t/m^3
10	Face height	h	3.70 m
11	Cutting slice depth	B	0.80 m
12	Face length	L	100 m
13	Cycle production	Q_c	474 t
14	Shift length	T_s	360 min
15	Number of workers on the face per shift	n_a	11

TABLE 2

Face process analysis

TABELA 2

Analiza procesu w przodku

Symbol i	Work group or complex operations	Total work volume [man-minute/cycle]	Work consumption per meter of extracted slice [M_i]
01	Shearer revision and knife replacement	–	–
02	Slice cutting and surveillance during stops	–	–
1.	Section flitting	620	2.78
2.	Front leveling and control	210	0.53
3.	Base gallery intersection works	1,350	–
4.	Head gallery intersection works	1,000	–
5.	Conveyor flitting	300	0.75
6.	Roof netting works	–	3.23

3. *Modeling and determining the dependency functions of the face process.* Modeling will be done based on the methodological elements presented on paragraph 4.

For *model draft* there are specified the following technological and organizational relations between shearer works and manual works on the face:

- The works on the two galleries can be executed during the entire cycle (a cycle is considered shearer slice cutting including shearer reposition for cleaning), excluding the time for transport flitting. The manual works in each gallery start after the shearer is 5–7 meters away from them and end when the shearer gets back closer at the same distance.
- The shearer revisions start after the end of a cutting work cycle. Together with shearer revision the shearer knives are replaced. The standard time for this work is about 30 minutes. After that transport flitting is executed, followed by another slice cutting work.
- Support sections cleaning and flitting is done in the same time with slice cutting works. By the time the shearer revision starts all the sections need to be flitted.
- Front leveling and control is done during shearer works and is executed in the same rhythm as section flitting.

Figure 1 presents a real graphic for shearer movement on a face, while Figure 2 presents the notations and relations of the mathematical model.

It is assumed that τ unknown periods of time, destined to delay recovery between front support, leveling and control compared with shearer advancing, due to the differences between execution speeds, are necessary for each t_k period of shearer advance. These periods, necessary for section flitting and front leveling and control, are noted with τ_{1k} and τ_{2k}, where $k \in v_1 > 0$ (v_1 representing shearer advance speed), periods representing only the t_k cutting periods and not the ones when the shearer is stopped. Between gallery intersection works and shearer works, may appear not allowed delays that have to be cleared on the last shearer cutting period, before reaching the destination gallery. There are only two delay recovery periods between the intersection works and slice cutting $\tau_{3k^{**}}$ and $\tau_{4k^{**}}$ (k^{**} representing the latest cutting periods before reaching the gallery intersections).

As a restriction, for the periods τ_{1k} and τ_{2k} the intersection works have to be done by the same workers as for previous k periods. On delay recovery for complex operations periods there can be used only $(z - b_1)$, $(z - b_2)$ ... $(z - b_6)$ workers (where z represents the number of workers on the face, while $b_1, b_2, ..., b_6$ – number of workers that cannot take part to the complex operations for delay recovery).

There are admitted as inevitable the shearer stops due to malfunctioning or due to external face problems (transport network).

For *face workers regrouping during stops*, due to above causes, there are proposed the following actions:

- For interruptions in shearer works with time length less than 10 minutes, worker distribution for complex operations is the same as for the period when the shearer worked.
- For shearer stops with time length over 20 minutes on the front section less than 30–40 meters closer to the intersections, a part of the workers on front support, leveling and control with the shearer mechanic can do the face roof netting works or the intersection works if there is available work front for it. For the case of analyzed face, on worker distribution on intersection, there are imposed the following placement limits: up to 4 workers on the transport gallery intersection, up to 4 workers on the ventilation gallery intersection.
- During other stops that don't correspond to the mentioned categories, the men that do metallic roof netting works can pass to section flitting and vice-versa. Also the shearer mechanic can work among them.
- Except the shearer interruption periods, the intersections will present a constant number of workers.
- During the shearer revision and conveyor flitting, the entire unit working on the shearer will remain there.
- During the delay recovery periods for different works, one single worker will stay at the shearer. The intersection workers will not work on front leveling and control.

The correlations between shearer works and manual works and the workers distribution rules on complex operations during shearer interruptions have the particular character of the analyzed face. These can be modified if another case presents other particularities. Generally, for any mechanized face these relations and rules need to exist.

As shown on paragraph 4, the model can be built for a simulated cycle or for a "mathematical expectance cycle".

According to the above conditions we will have the following face cycle phases (Fig. 2):

- shearer revision and knife replacement (30 minutes standard),
- conveyor flitting (30 minutes standard – participating 2 workers including the shearer workers),

- shearer interruptions with time length less than 10 minutes T_{01},
- shearer interruptions with time length over 10 minutes but less than 20 minutes on the front section 30–40 meters away from the destination gallery intersection, T_{02},
- shearer interruptions with time length over 20 minutes on the front section 30–40 meters away from the destination gallery intersection, T_{03},
- lengthening the cycle period for delay recovering, $\sum \tau$.

For the analyzed face the timing observations determined the following parameters of the probabilistic laws for shearer interruption appearances:

$\mu(m_l)$ – mean frequency for interruption appearance on a front section with length l cut by the shearer

$$\mu(m_l) = \rho \cdot l$$

where:

ρ – represents the mean frequency for interruption appearance for 1 meter of shearer advance ($\rho = 0.045$),
l – length of the slice cut by the shearer, used to determine the mean number of interruptions,
$f(t_0)$ – density probability function of the repartition law for interruption length,
t_0 – random variable, length of a shearer work stop.

For the analyzed face we use the repartition law that has the function equation:

$$f(t_0) = \frac{\lambda^n}{\Gamma(\eta)} t_0^{\eta-1} e^{-\lambda t_0}$$

with parameters λ and η.

The and of the repartition law were determined when the empiric repartition adjusting equation was established ($\lambda = 0.03$, $\eta = 0.36$).

To establish the model restriction we need to determine the mean period lengths of the phases that have probabilistic character:

- mean time length of a slice cut: $T_t = \dfrac{L-l}{\bar{v}_1}$ [minutes / run],

  where $\bar{v}_1$ is the shearere mean advance speed [meters / minute],
- mean length of the sum of shearer interruptions with time length less than 10 minutes:

$$T_{01} = \mu\left(\sum_k t'_{0k}\right) = \mu(m_l)\int_0^{10} t_0 f(t_0) dt_0 = \rho \cdot L \int t_0 \frac{\lambda^n}{\Gamma(\eta)} t_0^{\eta-1} e^{-\lambda t_0} dt_0 \text{ [minutes / run]},$$

- mean length of the sum of shearer interruptions with time length over 10 minutes but less than 20 minutes on the front section closer than 40 meters to the destination gallery:

$$T_{02} = \rho \cdot L \int_{10}^{\infty} t_0 \frac{\lambda^{\eta}}{\Gamma(\eta)} t_0^{\eta-1} e^{-\eta t_0} dt_0 - \rho \cdot 40 \int_{20}^{\infty} t_0 \frac{\lambda^{\eta}}{\Gamma(\eta)} t_0^{\eta-1} e^{-\eta t_0} dt_0 \quad \text{[minutes / run]},$$

- mean length of the sum of shearer interruptions with time length over 20 minutes on the front section closer than 40 to the destination gallery:

$$T_{03} = \rho \cdot 40 \int_{20}^{\infty} t_0 \frac{\lambda^{\eta}}{\Gamma(\eta)} t_0^{\eta-1} e^{-\eta t_0} dt_0 \quad \text{[minutes / run]}.$$

The input data mentioned above and in Tables 2 and 3 are replaced in the mathematical model of the face process presented in paragraph 4.

TABLE 3

File for assessing the technical standard requirements for the mechanized complex TAGOR and normed shifts for daily advance from Lupeni Mining Exploitation

TABELA 3

Plik do oceny wymogów norm technicznych dla zmechanizowanego kompleksu TAGOR i zmian normowych w postępach dziennych w Lupeni Mining Exploitation

No.	Maining operations's denomination	Normed shifts for cutting cycle (0.8 m)	Normed shifts for daily advance (1.81 m)
1	Shearer cutting	1.78	4.039
2	Manual loading	5.87	13.325
3	Cutting the space between the face and roof	1.31	2.968
4	Manual loading for the space between the face and roof	0.21	0.467
5	Roof pressure control	2.53	5.742
6	Section units cleaning	1.08	2.446
7	Section units relocation	7.37	16.732
8	Face conveyor flitting	1.84	4.176
9	Base conveyor shortening	0.35	0.797
10	Wooden set mouting in the lower entry	3.38	7.666
11	Wooden set mouting in the upper entry	0.32	0.715
12	Lining drawing in the lower and upper entries	1.70	3.847
13	Roof netting works	3.23	7.336
14	Face equipments maintenance	4.24	9.616
	TOTAL NUMBER OF SHIFTS	35.21	79.88
	TOTAL REALIZED SHIFTS (January 2008)		77.80

4. *Choosing and developing the optimal solution.* The model obtained above describes a non-linear mathematical programming problem. The model unknowns are z, x_{ik}, x_{nk}, T_c, τ_{ik} while z, x_{ik} şi x_{nk} are variables that can take only discrete number values.

The solution of the mathematical programming model is obtained using the *optimization toolbox* from the MATLAB programming menu.

Very important for solving the model is the relation between the number of workers on the face and the cycle length T_c. Because of this relation we can establish the variance limits of the solution.

The lower limit is given by the number of workers on the shearer x_{ok}, so $z \geq x_{0k}$.

The upper limit is obtained if the delay recovering period is zero, $\sum \tau = 0$ and results a mimimum cycle length and the maximum daily production on the face.

Applying the longwall face organizational simulation model, Lupeni Mining Exploitation obtained in January 2008 a total number of shifts shown in Table 3.

Conclusions

1. The described methodology allows accomplishing a large part of the theoretical objectives and requirements of usage optimization and work distribution on activities, by introducing a kind of relations resulted from considering the restrictions of work factors usage.
2. The investigated methodology allows both the descriptive and the decision-optimizing approach, giving the mining face process management an easy to use instrument that has a positive impact over obtaining a good economical result of the exploitation starting from the restrictions and limits given by the current work factors part of the process.
3. The presented methodology contributes to obtaining a better time organization and planning for the mining face process activities, characterized by a close to optimal utilization of the available quantities of potential production factors.
4. An important advantage of the methodology is given by the possibility of integrating it in the calculation algorithms of the limited substitution possibility for allocated production factor categories; this gives the premise of speeding up an activity by utilizing a different production factor category than normal (for example a category of personal with different qualification) when the face work technological restrictions allow it.
5. The proposed methodology gives the operative management of basic mining processes an decision instrument of planning, programming and adapting the face technological work process for obtaining a high economical efficiency.
6. It can be studied how the mining production factor results are translated in cost factors for an economical approach.
7. The practical methods for optimizing the usage levels and allocating the available factors for basic mining processes will be the objective of a future research.

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SYMULACJA ZŁOŻONEGO SYSTEMU ZMECHANIZOWANEGO UŻYTKOWANIA PRZODKA ŚCIANOWEGO

Słowa kluczowe

Złożone zmechanizowane przodki ścianowe, warunki geologiczno-górnicze, język MATLAB, kryteria optymalizacji rozwiązań organizacyjnych [red.]

Streszczenie

W przypadku złożonych zmechanizowanych przodków ścianowych, uwzględniając zarządzanie produkcją w kopalniach węgla, opracowano kilka rodzajów prostych sposobów modelowania procesu. Istniejące modele nie pozwalają na wyłączenia. Proponowany model jest oparty na dopuszczeniu przypadkowego charakteru wyłączenia urządzeń z użytkowania. Średnia długość faz jest obliczana dla każdego przodka, na podstawie praw prawdopodobieństwa i częstotliwości występowania trzech rodzajów wyłączeń i z uwzględnieniem prędkości postępowej maszyny. Aby uzyskać rozwiązanie modelu zastosowaliśmy oprogramowanie oparte na języku MATLAB.

THE SIMULATION OF LONGWALL COMPLEX MECHANIZED OPERATING FACE SYSTEM

Key words

Complex mechanized longwall faces, geological-mining conditions, MATLAB language, optimizing criteria of organizing solutions [red.]

Abstract

For complex mechanized longwall faces, in view of production management in collieries, several kinds of simple process modeling were developed. Existing models don't allow breakings. The proposed model is based on allowing the accidental character of breakings of the equipment's operation. For every face, the average length of the phases is calculated, based on the probability laws and occurrence frequency for three types of breakings and considering the equipment's advancing speed. To solve the obtained model, we used a software based on MATLAB language.