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METHOD OF THE PRODUCTION CYCLE DURATION TIME MODELING WITHIN HARD COAL LONGWALL FACES

METODA PROBABILISTYCZNEGO MODELOWANIA CZASU TRWANIA CZYNNOŚCI CYKLU PRODUKCYJNEGO REALIZOWANEGO W PRZODKACH ŚCIANOWYCH KOPALŃ WĘGLA KAMIENNEGO

Method of probabilistic modeling of the production cycle duration time within hard coal longwall faces has been described in the present study. Duration of these activities for various technologies, including probabilistic schemes modeling have been described in the introduction.

In order to illustrate the described method, an example of probabilistic modeling for data obtained from specific longwall face has been presented. The final chapters entitled "The possibility of Using the method" and "Results" contain information on the perspective of the method application in mining industry.

Keywords: longwall faces, production cycle, probabilistic modeling, probability density function, daily output

Treścią pracy jest metoda probabilistycznego modelowania czasu trwania czynności cyklu produkcyjnego realizowanego w przodku ścianowym kopalń węgla kamiennego. W części wstępnej scharakteryzowano modele czasu trwania czynności dla różnych technologii oraz schematy modelowania probabilistycznego stosowane w metodzie.

W celu ilustracji opracowanej metody podano przykład modelowania probabilistycznego z wykorzystaniem danych konkretnego przodka ścianowego. Końcowe rozdziały: Możliwości wykorzystania metody oraz wnioski końcowe zawierają informacje o perspektywach stosowania metody w praktyce górniczej.

Słowa kluczowe: przodki ścianowe, cykl produkcyjny, probabilistyczne modelowanie, funkcje gęstości prawdopodobieństwa, wydobycie zmianowe

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1. Introduction

Production process, realized within hard coal mine longwall faces, are characterized by influence of various factors, which are not observed in other production processes. These factors depend on technical-organizational, as well as geological-mining conditions.

Specific technical-organizational conditions comprise among the others the use of machines and devices, which co-operate in the process in a certain way, depending on the applied technology (shearer – support – conveyor), including time needed for reaching the working face. From the other side, geological and mining conditions may constitute impediments of the production process, which is realized in specific conditions, i.e. underground mining.

Production cycle executed within a hard coal mine working face is defined as group of operations repeated in a specific order and time, which is needed for working face advance by a single web distance (Kozdrój & Kozdrój-Weigel, 1993). After the end of the cycle personnel repeats this group of operations, i.e. execute the next cycle. Thus repeatability is a characteristic feature of the cycle. If one cycle per shift (24 hours) is executed within the working face, the work is called as mono-cyclic, whereas if *n* cycles per shift are executed the work is called as multi-cyclic.

In the year 2009 (according to data of Polish Mining Institute), 221 working faces were operated in Polish mining industry (yearly report – 2010).

Among them, 98% of the working faces was mined in roof cut and fill system and 2% by shearer with hydraulic back filling.

Based on the above statistics we can conclude that 98% of working faces is operated in roof cut and fill system, where shearers are used as mining machines. Stream-flow form of the work organization is used in these working faces being characterized by realization of a number of production cycled per shift (24 hours).

2. Probabilistic models of the production cycle duration

Realization of the production cycle comprises execution of a number of activities related with coal roc body cutting, as well as with the support, including proper handling of the longwall – left and right roadway crossing. From the technological point of view all works are important, but not all of them directly influence the production cycle duration time (Snopkowski, 1994).

Thus, activities having direct influence onto production cycle duration have been selected.

Rule of continuous shearer operation is a general rule, which is applied within the working faces equipped with shallow-web shearers. The rule in question should be understood in such manner, that for example, if the shearer is moved along the longwall cutting the coal rock body, its movement should not be stopped, for example by inadequately fast moved support, or by other works, which should be executed in parallel (Snopkowski, 1990, 2000).

In case of modern longwall working face works organization, the operational rate is determined by the shearer. The shearer produces the winning and each stoppage if its advance is disadvantageous, because it reduces the production process effectiveness. Only technology-related stoppage of the shearer advance is permissible. Such situation takes place for example at the moment of driving unit or turning station replacement, when the shearer waits for the execution of these activities.

Based on the above suggestions, formulas defining the production cycle duration for one-way and two-way mining, have been formulated, what allows specifying the set of activities, which influence the cycle duration time directly (Snopkowski, 1997). Manner of calculation of this time for two-way shearer mining is shown below.

Production cycle for such mining technology is shown in Fig. 1. The cycle comprises all activities and operations, which are needed for coal mining on the whole longwall length, for a single web depth, where the longwall conveyor drive units are set in perpendicular system.

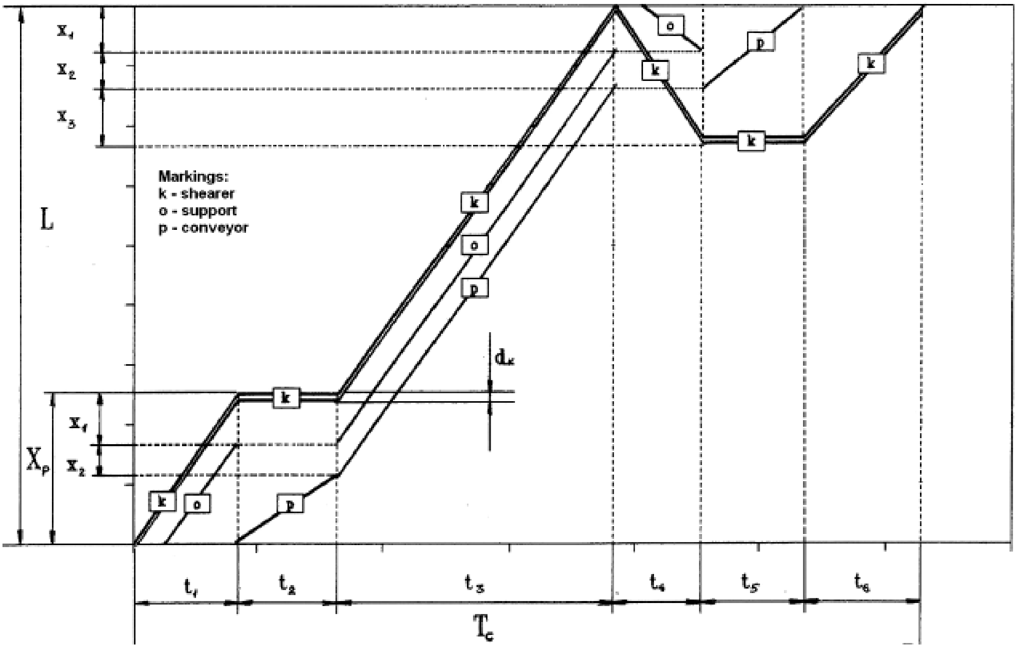

Fig. 1. Scheme of the production system for two-way mining technology with use of the shearer (Snopkowski, 1997)

The following symbols are used in Fig. 1

L — longwall length [m],

T_c — production cycle duration [min],

$t_1, t_2, ..., t_6$ — time of completion of the production cycle elements of [min],

d_k — shearer length [m],

x_1, x_2, x_3 — adequate distances of executed activities and operations within the system shearer – support – conveyor [m],

x_p — distance between shearer stoppage place and longwall-roadway crossing [m].

Production cycle duration is defined as a sum of the individual elements realization times:

$$T_c = t_1 + t_2 + t_3 + t_4 + t_5 + t_6 \tag{1}$$

In order to calculate the time t_1 the shearer advance rate V_{cz} during cleaning the longwall section of the length $x_p - d_k$ is used, thus

$$t_1 = \frac{1}{V_{cz}} \cdot (x_p - d_k) \tag{2}$$

Time t_2 (as t_5) is not dependent on any of elements of the shearer – support – conveyor system. Times t_2 and t_5 are turning station (drive unit) replacement times, beginning from the moment of the props leaving, up to the moment of their spacing after full web shift. All works connected with crossing rebuilding (removal of roadside arcs from the longwall side, eventual replacement of rails reinforcing the crossing, removal of nets) are executed apart the time moment equal to t_2 (t_5).

Time t_3 is calculated from the formula

$$t_3 = \frac{1}{V_r} \cdot (L - x_p) \tag{3}$$

In time t_4 the shearer is slotted in direction toward the longwall centre. Thus while calculating the time t_4, we should take under consideration advance rate of the slotting shearer. Marking this rate as V_z we obtain

$$t_4 = \frac{1}{V_z} \cdot (x_1 + x_2 + x_3 - d_k) \tag{4}$$

where:

V_z — advance rate of the slotting shearer [m/min]
$x_1 = d_k + s$ [m],
s — distance between support and shearer [m],
x_2 — distance between shifted conveyor and support [m],
$x_3 = d_k + p$ [m],
p — minimal distance between shifted conveyor and shearer [m].

Time t_5 – time of the turning station (driving unit) replacement is calculated analogically as was explained in case of time t_2.

In time t_6 the shearer cuts the coal rock body moving toward the longwall end, thus shearer marked as V_r, is used for calculation

$$t_6 = \frac{1}{V_r} \cdot (x_1 + x_2 + x_3 - d_k) \tag{5}$$

Substituting to formula (1) we obtain:

$$T_c = \frac{1}{V_{cz}} \cdot (x_p - d_k) + \frac{1}{V_r} \cdot (L - x_p) + \left(\frac{1}{V_z} + \frac{1}{V_r} \right) \cdot (x_2 + d_k + p + s) + t_2 + t_5 \tag{6}$$

The formula is a sum of duration time of the following activities:
- cleaning with use of the shearer within a section $(x_p - d_k)$,
- cutting with use of the shearer within a section $(L - x_p)$,
- slotting with use of the shearer within a section $(x_2 + d_k + p + s)$,
- cutting with use of shearer within a section equal to $(x_2 + d_k + p + s)$,
- turning station replacement,
- driving unit replacement.

The above activities of the production cycle (calculated from formula (6) are used in probabilistic modeling of the duration of these activities conducted within longwall working faces, in which two-way cutting (mining) with use of shearer is applied.

Acting analogically as in case of two-way shearer mining, we can derive a formula for the production cycle duration for the longwall working face, in which one-way shearer mining is applied.

The formula was derived for complex-mechanized longwall working faces, led without cavities. Mining is executed with use of the shearer on whole longwall length and drive units of longwall conveyor are set perpendicularly.

Production cycle for one-way mining technology, which comprises all activities and operations needed for coal mining on whole longwall length with single web depth, is shown in Fig. 2.

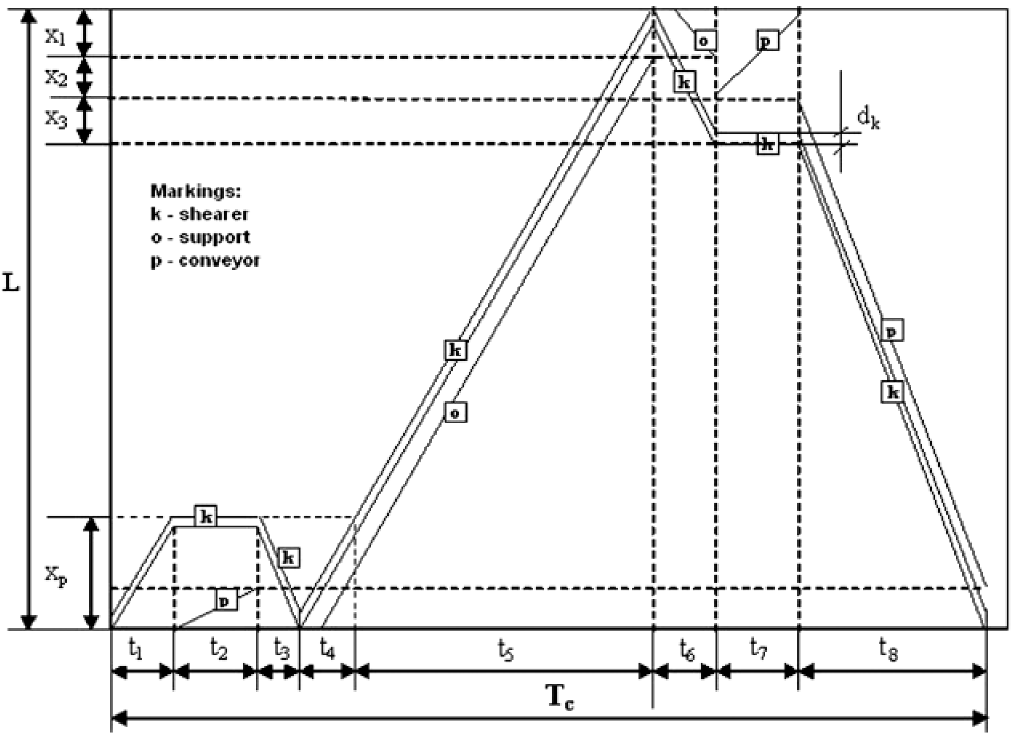

Fig. 2. Scheme of the production cycle for one-way mining technology with use of the shearer (Snopkowski, 2000)

The following symbols were used:

L — longwall length [m],

T_c — production cycle duration time [min],

$t_1, t_2, ..., t_8$ — times of the execution of the production cycle individual elements [min],

d_k — shearer length [m],

x_1, x_2, x_3 — mutual distances of the executed activities and operations within a system shearer – support – conveyor [m],

x_p — distance between shearer parking place and the longwall – roadway crossing [m].

Duration of the production time is a sum of times of individual cycle fragments realization, thus

$$T_c = t_1 + t_2 + t_3 + t_4 + t_5 + t_6 + t_7 + t_8 \tag{7}$$

In time marked in the Fig. 2 as t_1, shearer cutting the coal rock body is moved toward the longwal centre. In order to calculate t_1 we can use formula:

$$t_1 = \frac{1}{V_z} \cdot (x_p - d_k) \tag{8}$$

where: V_z — shearer advance rate [m/min],

The other calculations as above.

Time t_2 (like t_7) is a time of the drive unit (turning station) replacement, beginning from the moment the pillars removal up to the moment of their sprag, after single full web shift. Any works related with the crossing rebuilding are executed beyond the time moment $t_2(t_7)$.

Time t_3 is a time, in which slotted shearer cuts the coal rock body, being moved on conveyor located by the longwal, in direction toward the longwall – roadway crossing. This time may be calculated from a formula:

$$t_3 = \frac{1}{V_r} \cdot (x_p - d_k) \tag{9}$$

where: V_r — shearer operational advance rate [m/min].

In time t_4 shearer prepares the shearer route along a section $(x_p - d_k)$, thus

$$t_4 = \frac{1}{V_{cz}} \cdot (x_p - d_k) \tag{10}$$

In time t_5 the shearer cuts the coal rock body being moved toward opposite crossing with roadway, thus

$$t_5 = \frac{1}{V_r} \cdot (L - x_p - d_k) \tag{11}$$

After the coal rock body is cut, cleaning of the shearer route is executed. Thus time t_6 may be calculated from a formula:

$$t_6 = \frac{1}{V_{cz}} \cdot (x_1 + x_2 + x_3 - d_k) \tag{12}$$

where:

V_{cz} — shearer maneuver advance rate (shearer advance rate during cleaning the shearer route) [m/min],

$x_1 = d_k + s$ [m],

s — distance between shifted support and shearer [m],

x_2 — distance between shifted conveyor and support [m],

$x_3 = d_k + p$ [m],

p — minimal distance between displaced conveyor and shearer [m].

Time t_7 is time needed for drive unit (turning station) displacing – its calculation is analogue as in case of the time t_2.

After the drive unit (turning station) displacing, the shearer starts movement toward the longwall end, cleaning the shearer route in time t_8. Thus

$$t_8 = \frac{1}{V_{cz}} \cdot (L - x_1 - x_2 - x_3) \tag{13}$$

Substituting expressions from formulas from (8) to (13) into formula (7), we obtain a formula describing duration time of the production cycle for technology of one-way cutting with use of the shearer, in form:

$$T_c = \left(\frac{1}{V_z} + \frac{1}{V_r} + \frac{1}{V_{cz}}\right)(x_p - d_k) + \frac{1}{V_r}(L - x_p - d_k) + \frac{1}{V_{cz}}(L - d_k) + t_2 + t_7 \tag{14}$$

Duration times of the following activities occur in the above formula:

- slotting with shearer within a section $(x_p - d_k)$,
- cutting with shearer within a section $(x_p - d_k)$,
- cleaning with shearer within a section $(x_p - d_k)$,
- cutting with shearer within a section $(L - x_p - d_k)$,
- cleaning with shearer within a section $(L - d_k)$,
- turning section displacing,
- drive unit displacing.

Complexity of natural conditions occurring within coal basins considerably influences mining output and production cycle. These conditions are even worse within the coal basins with complicated and disturbed tectonics, as well as within the areas characterized with mining hazards, like crump tendencies, gas squealers and coal outbursts, fires etc.

Methods for detrmining the influence of geological and mining conditions, as well as technical and organizational conditions onto shearer-based mining, or onto duration of other operations conducted within the longwal face, have been described in the literture. Regression and corellation calculus is used for that purpose. However, observation of real process proved that parameters obtained in result of application of these methods do not keep constant values in the production process. Thus it is assumed that time of realization of these activities may (but does not need to) be changed in each production cycle. In consequence it was accepted that this time is a random variable, which may be desrcibed by the probability density function. These functions for formulas (6) and (14) have the following symbols:

$f(V_r)$ — operational advance rate density function of shearer,
$f(V_z)$ — operational advance rate density function of slotted shearer,
$f(V_{cz})$ — operational advance rate density function of maneuvering shearer,
$f(x_p)$ — density function of the distance between shearer parking place and longwall-roadway crossing,
$f(x_2)$ — density function of the distance between shifted conveyor and support,
$f(s)$ — density function of the distance between shifted support and shearer,
$f(t_2)$ — density function of the turning station displacement time,
$f(t_5)$ — density function of the drive unit displacement time (for two-way shearer-based mining),
$f(t_7)$ — density function of turning station displacement (for one-way shearer-based mining).

Schemes of probabilistic modeling for two and one-way shaerer-based mining technology are show in Figures 3 and 4. In result of the applied algorithms we obtain an assemblage of generated durations of the production cycle $\{T_c^1; T_c^2; ...; T_c^n\}$.

Schemes shown in Fig 3 and 4 illustrate procedures of generation of production cycle duration times with an assumption that all parameters are described with probability density functions. However, if the conditions of process, which is realized within definite longwall face indicate that part of these parameters have determined character. In such case procedure shown in Fig. 3 or 4 is limited only to those parameters, which are described with adequate density functions.

In result of the application of scheme shown in Fig. 3 or 4, we obtain assemblage $\{T_c^1; T_c^2; ...; T_c^n\}$ of production cycle duration times.

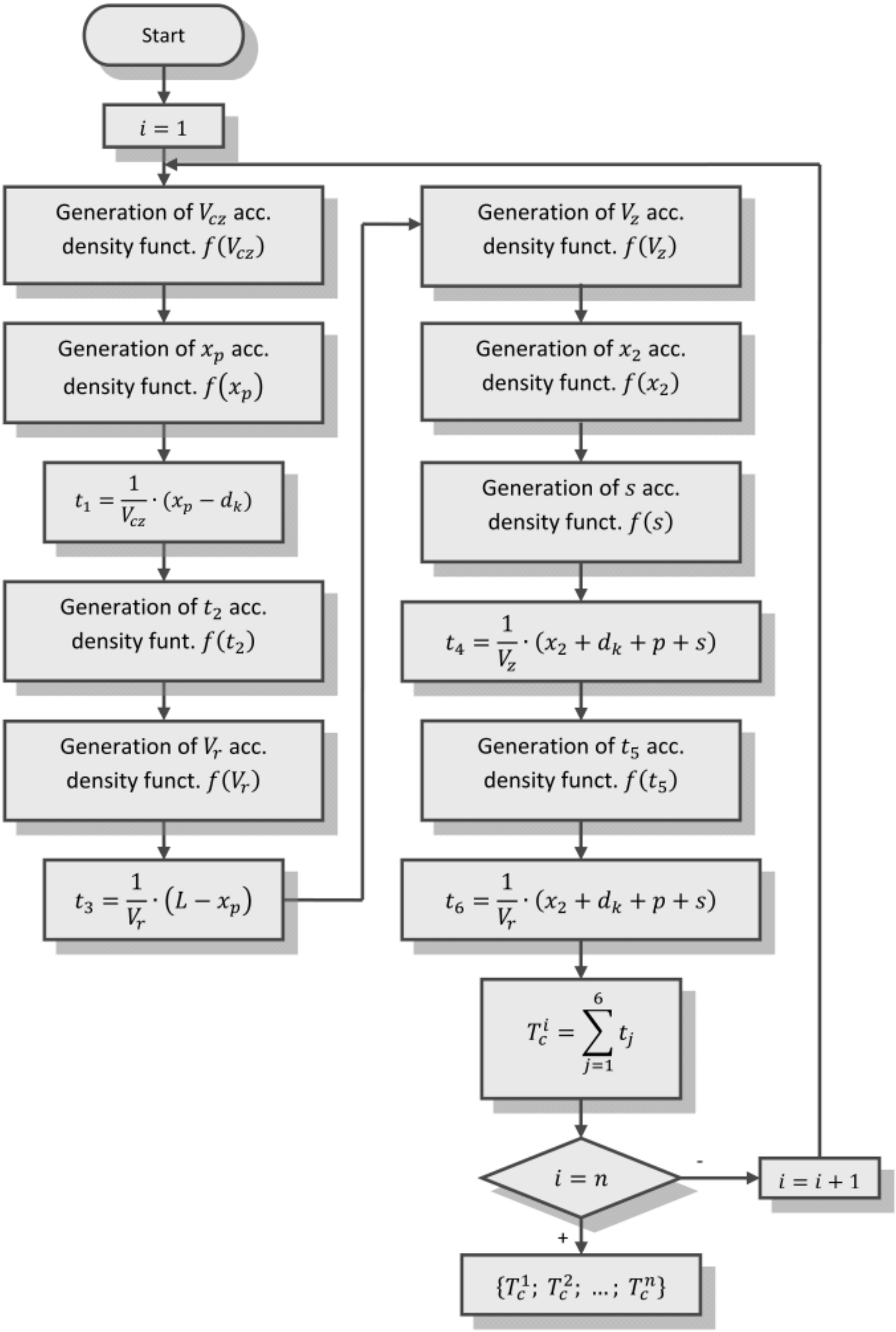

Fig. 3. Scheme of the probabilistic modeling for shearer-based two-way mining technology, leading to obtaining times of the production cycle duration $\{T_c^1; T_c^2; \ldots; T_c^n\}$ (Napieraj, 2011)

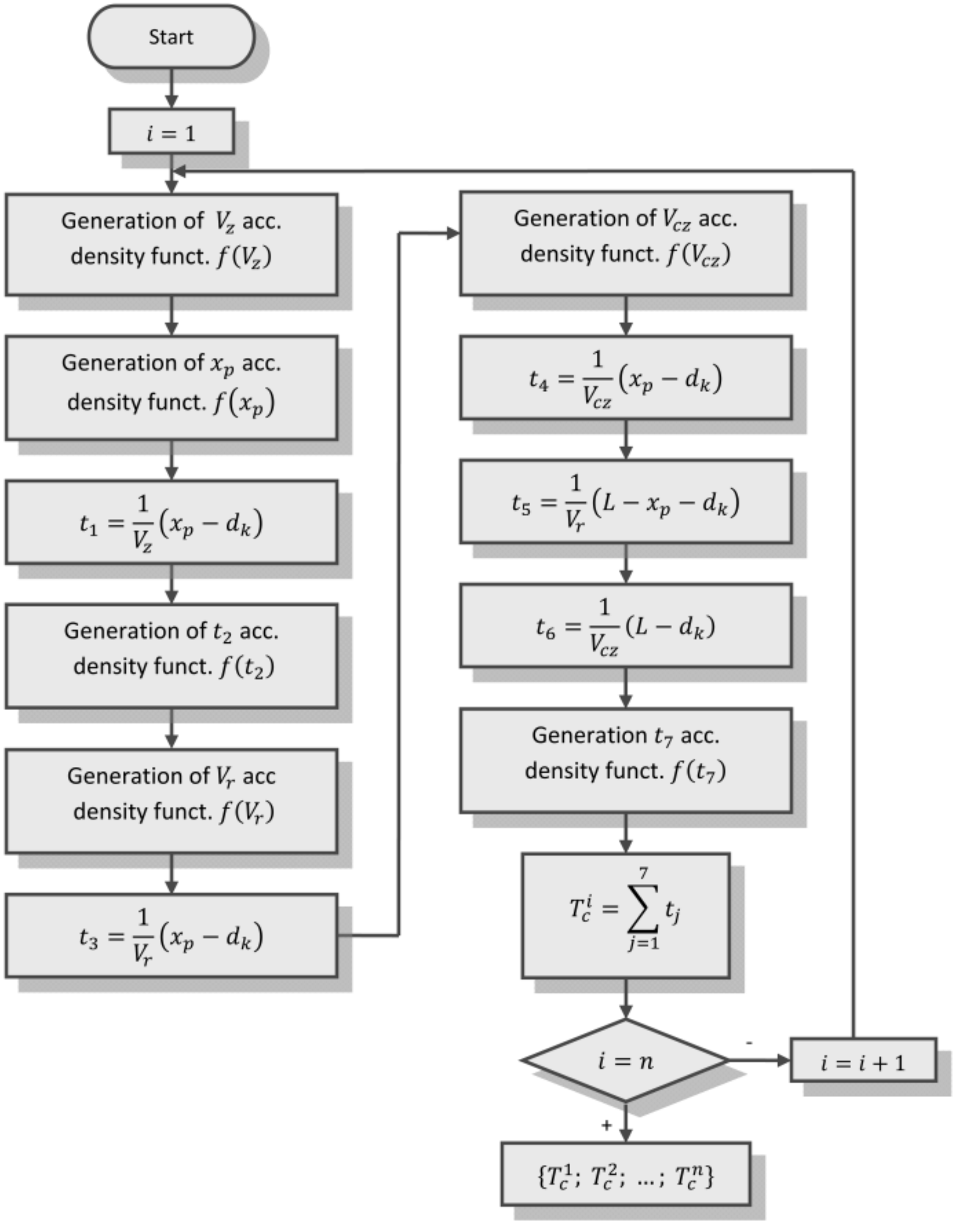

Fig. 4. Scheme of probabilistic modeling for shaerer-based one-way mining, leading to obtaining the times of the production cycle durations $\{T_c^1;\ T_c^2;\ \ldots;\ T_c^n\}$ (Napieraj, 2011)

3. An example of probabilistic modeling of the production cycle duration times for a specific longwall face

The example was developed on the basis of data obtained from the longwall face of coal seam No. 209 of the Łaziskie beds, in which the exploitation was conducted using longwall system roof cut and fill.

The longwall was mined in two-way system. General parameters are cited in Table 1. Mining and geological conditions occurring in the longwall are presented in Table 2.

TABLE 1

General parameters of the tested longwall face

General parameters of the longwall	Value
Longwall length	220 m
Longwall height	4,0-4,4 m
Longwall stopway	1700 m
Maximal web	0,8 m
Longwall inclination: – longitudinal (along the longwall) – transverse (along the stopway)	 0°-2° 0°-2°
Thickness of the coal layer in the roof	do 0,3 m
Thickness of the coal layer in the floor	do 0,2
Exploitation depth	710-690 m

TABLE 2

Mining and geological conditions occurring within the longwall face

Specification	Value
Coal seam thickness	4,0-4,4 m
Roof	0,0-6,2 m clayey shale
Basic roof	37,7-43,2 m multi-grained sandstones
Coal seam floor	1,5-2,4 m clayey shale
Coal type	31,2
Coal specific weight (mean)	1,35 g/m^3

Technical equipment of the longwall was adapted to mining and geological conditions. Basic elements of this equipment comprised: longwall shearer KSW-2000E, push-plane conveyor RYBNIK 1100, longwall crusher KS-2, push-plane conveyor GROT 1100, crusher SKORPION 3000P with belt drive, returnable device UPP-3, mechanized support FAZOS-22/45-POz, mechanized support FAZOS-22/45-POz/BSN and pumping unit EHP-3K 125/62.

Chronometric examinations of chosen characteristics have been executed within the longwall face. Obtained results were statistically tested.

Characteristics of these data are gathered below. The comparison consists of specified values and adequate functions having properties of the probability density functions.

Specified data are as follow:

L — longwall length, $L = 220$ [m],

d_k — shearer length 10 [m],

x_2 — distance between conveyor and support, $x_2 = 3{,}2$ [m],

p — minimal distance between movable conveyor and shearer, $p = 5{,}25$ [m].

For data of specified character the following functions were defined: $f(V_{cz})$, $f(V_r)$, $f(V_z)$, $f(t_2)$, $f(t_5)$:

■
$$f(V_{cz}) = \frac{f^*(V_{cz})}{F(22) - F(4{,}5)} \tag{15}$$

where:

V_{cz} — shearer maneuver advance rate (shearer advance rate during the shearer route cleaning) [m/min],

$F(22)$, $F(4{,}5)$ — cumulative distribution function in adequate points for function:

$$f^*(V_{cz}) = \frac{1}{3{,}58\sqrt{2\pi}} e^{-\frac{(V_{cz}-9{,}7)^2}{2(3{,}58)^2}} \tag{16}$$

■
$$f(V_r) = \frac{f^*(V_r)}{F(6{,}7) - F(1{,}8)} \tag{17}$$

where:

V_r — shearer operational advance rate [m/min],

$F(6{,}7)$, $F(1{,}8)$ — cumulative distribution function in adequate points for function:

$$f^*(V_r) = \frac{1}{1{,}2\sqrt{2\pi}} e^{-\frac{(V_r-3{,}7)^2}{2(1{,}2)^2}} \tag{18}$$

■
$$f(V_z) = \frac{f^*(V_z)}{F(11{,}5) - F(2{,}3)} \tag{19}$$

where:

V_z — slotted shearer advance rate [m/min],

$F(11{,}5)$, $F(2{,}3)$ — cumulative distribution function in adequate points for function:

$$f^*(V_z) = \frac{1}{1{,}8\sqrt{2\pi}} e^{-\frac{(V_z-5{,}8)^2}{2(1{,}8)^2}} \tag{20}$$

■
$$f(t_2) = \frac{f^*(t_2)}{F(15) - F(4)} \tag{21}$$

where:

t_2 — time of turning station shift [min],

$F(15)$, $F(4)$ — cumulative distribution function in adequate points for function:

$$f^*(t_2) = \frac{1}{2{,}3\sqrt{2\pi}} e^{-\frac{(t_2-7{,}8)^2}{2(2{,}3)^2}} \tag{22}$$

■

$$f(t_5) = \frac{f^*(t_5)}{F(30)-F(6)} \tag{23}$$

where:

t_5 — time of the drive unit shift [min],

$F(30)$, $F(6)$ — cumulative distribution function in adequate points for function:

$$f^*(t_5) = \frac{1}{4{,}9\sqrt{2\pi}} e^{-\frac{(t_5-11{,}8)^2}{2(4{,}9)^2}} \tag{24}$$

Whereas, x_p and s were described as follow:

- x_p – distance between the shearer parking place and longwall-roadway crossing [m], which is changed in the real process within the range 15-20 m. Uniform distribution with parameters $a = 15$, $b = 20$ was used for the variable x_p description.
- s – distance between shifted support and shearer [m], which is changed within range from 8 to 20 m. Based on the possessed data, triangular distribution with parameters $a = 8$, $b = 15$, $c = 20$ was taken as model of the distance s in the longwall face conditions, where the examinations have been executed.

Using the above data and scheme shown in Fig. 3, probabilistic modeling of production cycle duration times was developed for technology of two-way shearer-based mining. Number of simulations "n" was obtained on the basis of two-stage Stein procedure.

The modeling comprised generation of random numbers according to functions $f(V_{cz})$, $f(x_p)$, $f(V_r)$, $f(V_z)$, $f(s)$ $f(t_2)$, $f(t_5)$ and calculation of adequate times t_1 to t_6 according to formulas shown in Fig. 3. Based on values t_1 to t_6, production cycle duration time T_c was calculated. This procedure was repeated "n" times. Von Naumann's elimination was used for generation of the numbers according functions $f(V_{cz})$, $f(V_r)$, $f(V_z)$, $f(t_2)$, $f(t_5)$ whereas method of cumulative distribution function reversing was used for the other functions.

The executed statistical analysis proved that log-normal distribution is optimally approximated by the assemblage $\{T_c^1; T_c^2; ...; T_c^n\}$. Results of the analysis in graphical form are shown in Fig. 5.

Density function of production cycle log-normal duration time for parameters $\mu = 4{,}53$ and $\sigma = 0{,}21$ is:

$$f(T_c) = \frac{1}{0{,}21\sqrt{2\pi}\,T_c} \cdot e^{-\frac{(\ln T_c-4{,}53)^2}{2(0{,}21)^2}} \tag{25}$$

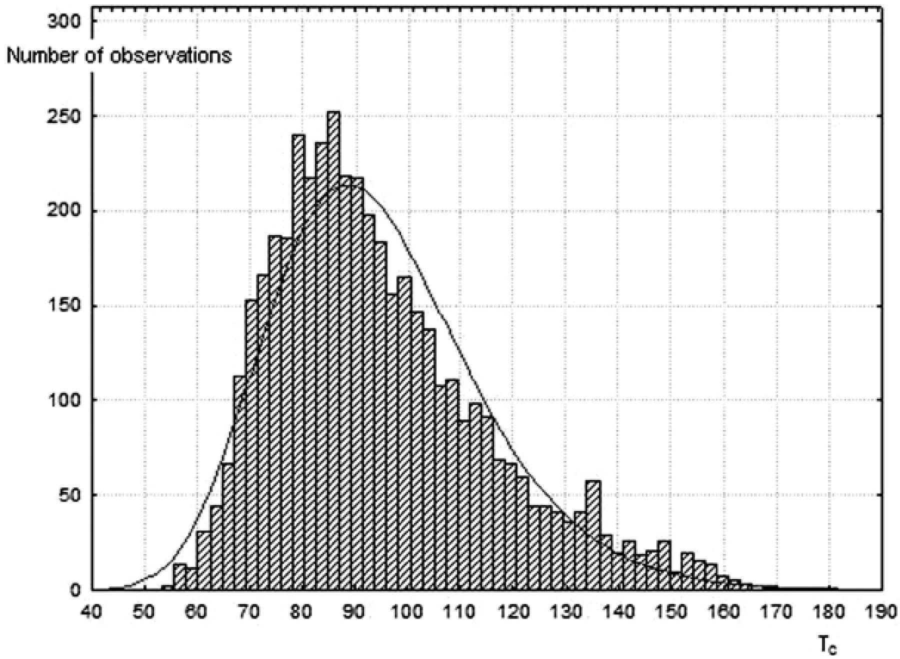

Fig. 5. Histogram of variable T_c and function $f(T_c)$

4. Options of practical use of the production cycle duration time probabilistic modeling

Level of the output obtained from longwall face depends not only on duration time of realized production cycle but also on for example: longwall height, shearer web, disposed time, what results from the following formula:

$$W_{zm} = \frac{T_d \cdot H \cdot z \cdot \gamma \cdot L}{T_c} \tag{26}$$

where:

- T_d — disposable shift time [min/shift],
- T_c — production cycle duration time [min],
- H — longwall height [m],
- z — shearer web [m],
- L — longwall length [m],
- γ — coal specific weight [Mg/m^3].

In conditions of longwall face, in which the chronometric observations were conducted, parameters mentioned in formula (26), is characterized by a certain variability. The variations comprise longwall height (fluctuation of abort 40 cm), shearer web (fluctuations of abort 10 cm) and disposable shift duration time (fluctuations of abort 30 min).

Suitable functions describing variability of mentioned parameters are gathered below. Suitable assumptions of individual function resulted from analysis of obtained chronometric data:

- H – longwall height [m]. In conditions of the longwall face, the longwall height of the section where chronometric measurements were conducted fluctuated within a range from 4 to 4,4 m. Thus uniform distribution with parameters $a = 4$; $b = 4,4$ was assumed as physical model of variable H,
- z – shearer web [m]. Uniform distribution with parameters $a = 0,7$; $b = 0,8$ was assumed as a function describing variable "z".
- T_d – disposable time [m/shift], which in case of tested longwall face was not constant. This time subjected to some fluctuations – a certain distance from pit shaft had to be overcame in order to reach the longwall face. It was assumed on the basis of conducted observations that uniform distribution with parameters $a = 340$, $b = 370$ will be taken for model describing variable T_d.

Procedure of daily output calculation comprised the use of previously determined production cycle duration time T_c, generation of random numbers according distributions $f(z)$, $f(T_d)$ and substitution these values into formula (26). After taking into account in the formula not changing values L and γ, daily output W_{zm} was calculated "n" times.

Obtained values of the daily output ("n" element assemblage) were tested statistically. The statistical analysis proved that continuous approximating function has character of normal distribution N(3664, 759). Histogram with approximating function is shown in Fig. 6.

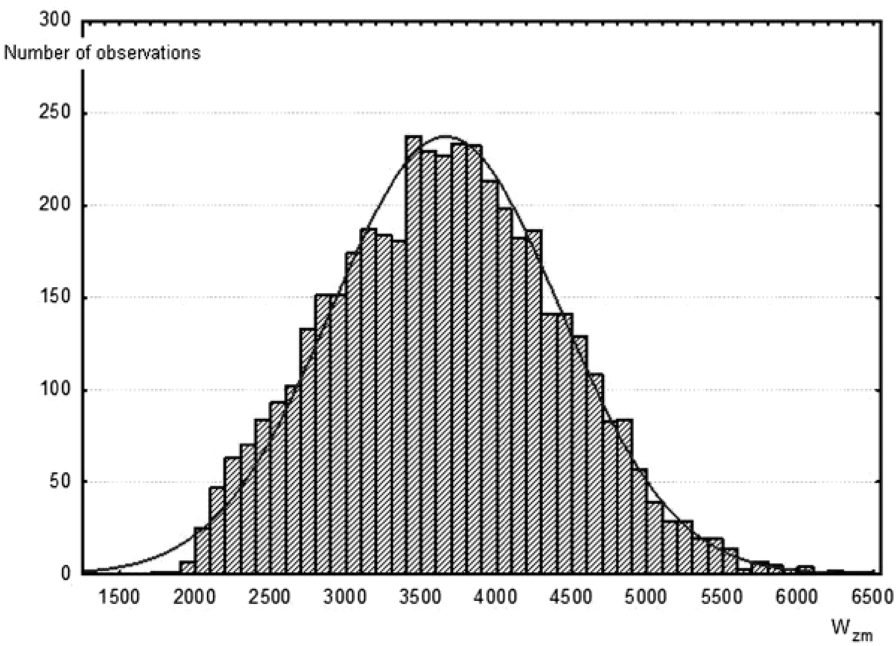

Fig. 6. Histogram of variable W_{zm} and function $f(W_{zm})$

Thus analytical form of the function describing longwall face daily output, in which chronometric examinations were conducted is expressed as:

$$f(W_{zm}) = \frac{1}{759\sqrt{2\pi}} \cdot e^{\frac{-(W_{zm}-3664)^2}{2\cdot 759^2}} \tag{27}$$

Using the above function we may solve the following problems:

Problem I

In conditions of given longwall face we may determine probability of exceeding daily operational output, which is equal to W_0.

In case of such attitude, we should solve the following equation:

$$P(W_{zm} > W_0) = 1 - \int_{-\infty}^{W_0} \frac{1}{759\sqrt{2\pi}} \cdot e^{\frac{-(W_{zm}-3664)^2}{2\cdot 759^2}} dW_{zm} \tag{28}$$

For example, if $W_0 = 5000$ [Mg/shift], after substitution to formula (28) and integration we obtain:

$$P(W_{zm} > 5000) = 0{,}039 \tag{29}$$

It results from calculations that in conditions of longwall face, in which the examinations were conducted, reaching daily output on level exceeding 5000 [Mg/shift] is unlikely, because probability of such event occurs only at the level of 0,039.

Problem II

In conditions of given longwall face we are able to determine probability that the daily output from this longwall face will fluctuate within range from W_1 to W_2, under assumption that $W_1 < W_2$.

I such case we should solve the following equation:

$$P(W_1 < W_{zm} < W_2) = \int_{-\infty}^{W_2} \frac{1}{759\sqrt{2\pi}} \cdot e^{\frac{-(W_{zm}-3664)^2}{2\cdot 759^2}} dW_{zm} + \\ - \int_{-\infty}^{W_1} \frac{1}{759\sqrt{2\pi}} \cdot e^{\frac{-(W_{zm}-3664)^2}{2\cdot 759^2}} dW_{zm} \quad 30)$$

For example, if $W_1 = 2500$ [Mg/shift], and $W_2 = 5000$ [Mg/shift], after substitution to formula (30) we obtain

$$P(W_1 < W_{zm} < W_2) = 0{,}802 \tag{31}$$

It results from the calculations that in conditions of longwall face, in which the examinations were executed, probability that obtained daily output larger than 2500 [Mg/shift] and smaller than 5000 [Mg/shift] amounts for 0,802. In this manner we may calculate probability for any output range.

5. Final conclusions

The following final conclusions have been drawn:

1) Modeling of production cycle duration times expressed in form of density function allows consideration of many factors influencing these activities. This influence results in variable time of their realization in conditions of specific longwall face.
2) The production cycle analysis with use of the density function of these activities duration time allows obtaining production cycle duration time expressed in form of a function.
3) Method of probabilistic modeling of production cycle duration time leeds to development of the shift output level not in the form of point, but density.
4) Function of the shift output density allows assessment of the longwall face production possibilities, what is very essential in a case of increasing production capacity.
5) Use of the shift output density function allows assessment of the probability of obtaining definite output level within a given longwall face.
6) Testing of several longwall faces with use of the method described in the present study allows assessment of the probability of obtaining a shift output of defined level within the area of exploitation section, or in terms of broader aspect, for whole mine. Thus the assessment of the output efficiency of given exploitation section or whole mine may be objectified. Solution referring to many production shifts has been described in a study by Snopkowski: Longwall output plan considered in probabilistic aspect.

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