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LONGWALL FACE CREW SELECTION WITH RESPECT TO STOCHASTIC CHARACTER OF THE PRODUCTION PROCESS – PART 2 – CALCULATION EXAMPLE

WYZNACZANIE OBSADY PRZODKA ŚCIANOWEGO Z UWZGLĘDNIENIEM STOCHASTYCZNEGO CHARAKTERU PROCESU PRODUKCYJNEGO CZ. 2 – PRZYKŁAD OBLICZENIOWY

A calculation example of the longwall face crew selection, including taking under consideration stochastic character of the production process is presented in this study. On the basis of observation of duration of activities realized in the hard coal mine longwall face with use of the roof cut and fill system, the calculations with use of the proposed crew selection method have been executed. The method in question takes into consideration stochastic character of the realized production process (Snopkowski & Sukiennik, 2012). In the final part of this study, graphical interpretation of the executed calculations has been presented.

Keywords: Crew selection of the longwall face, probability density functions, production cycle, longwall face

Zagadnienie wyznaczania obsady przodka ścianowego jest przedmiotem badań i analiz praktycznie od momentu rozpoczęcia stosowania systemu ścianowego w kopalniach węgla kamiennego. Metoda opisana w niniejszej pracy uwzględnia jednak czynnik dotychczas nie uwzględniany w opracowaniach z tego zakresu, a mianowicie stochastyczny charakter realizowanego w przodku procesu. Początki prac z zakresu analizy funkcjonowania przodków ścianowych z uwzględnieniem stochastycznego charakteru procesu produkcyjnego sięgają lat 90-tych, kiedy zaczęto wykorzystywać metodę symulacji stochastycznej jako metodę badawczą.

W części pierwszej publikacji (*Wyznaczanie obsady przodka ścianowego z uwzględnieniem stochastycznego charakteru procesu produkcyjnego cz. 1 – opis metody*), zamieszczono szczegółowy opis opracowanej metody. W niniejszym artykule przedstawiono przykład obliczeniowy, w którym wyznaczono obsadę dla warunków konkretnego przodka ścianowego.

Przykład opracowano na podstawie danych uzyskanych z przodka ścianowego, prowadzonego z zawałem stropu, którego charakterystykę zawiera tabela 1.

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Proces produkcyjny realizowany w analizowanym przodku ścianowym obejmował cykl produkcyjny oraz czynności i operacje związane z cyklem technologicznym. Cykl produkcyjny realizowany był w technologii dwukierunkowego urabiania kombajnem. Na rysunku 1 zaprezentowano schemat tego cyklu z wyodrębnionymi i zaznaczonymi modułami, które będą stanowiły podstawę dalszych obliczeń.

W ramach prac związanych z cyklem technologicznym wyznaczono obsadę prac, które przedstawiono na rysunku 2. Są to prace związane z przebudową skrzyżowania i korygowania położenia przenośników w związku z postępem ściany.

Na podstawie badań chronometrażowych przeprowadzonych w warunkach danego przodka ścianowego, przyjęto do dalszych obliczeń funkcje gęstości, opisujące czasy realizacji na odcinku 1 metra, poszczególnych czynności i operacji. Charakterystykę funkcji zamieszczono w tabeli 2.

Obliczenia, które przeprowadzono w celu wyznaczenia obsady procesu produkcyjnego wykonano dla każdego z wyodrębnionych modułów. Schemat obliczeń w ramach poszczególnych modułów przedstawia się następująco: w module pierwszym z wykorzystaniem wzorów 1 i 2, w module drugim z wykorzystaniem wzorów 3 i 4, w trzecim z wykorzystaniem wzorów od 5 do 17, w czwartym wzory od 18 do 20, w module piątym wzory od 21 do 23. Moduł szósty zawiera tylko jedną czynność, więc obsada jest przyjmowana w ilości dwóch pracowników. Dla modułu siódmego, wyznaczono 4 ścieżki pełne (tabela 3) a następnie dokonywano szereg obliczeń, które są zestawione w tabeli 4.

Wyniki przeprowadzonych obliczeń zamieszczono na rysunku 3.

Wyznaczona, za pomocą zaproponowanej w pracy metody, obsada przodka ścianowego, prowadzonego technologią dwukierunkowego urabiania kombajnem, jest obsadą zapewniającą ciągłą realizację procesu produkcyjnego w tym przodku, przy najmniejszej liczbie potrzebnych pracowników.

Zaproponowana metoda zakłada wykorzystanie funkcji gęstości prawdopodobieństwa czasów trwania czynności do wyznaczania obsady przodka wydobywczego. W metodzie wykorzystano odmienne od deterministycznego podejście, polegające na traktowaniu czasów realizacji czynności jako zmiennych losowych. Zastąpienie zmiennych deterministycznych zmiennymi losowymi pozwoliło na jednoczesne uwzględnienie, w postaci funkcji gęstości prawdopodobieństwa, wielu czynników wpływających na czas realizacji czynności.

Słowa kluczowe: wybór załogi dla ściany wydobywczej, funkcja gęstości prawdopodobieństwa, cykl produkcyjny, ściana wydobywcza

1. Introduction

First studies related with the analysis of the longwall face functioning taking into account stochastic character of the production process have been conducted in the nineties of the last century (Snopkowski, 1990, 1994). Research works comprising the analysis of the output obtained from the longwall taking into account probability distributions have been conducted in the next decades (Snopkowski, 2000a, 2000b, 2002). Method of the stochastic simulation was used as the research method (Snopkowski, 2005, 2007a, 2007b, 2009) and (Snopkowski, Napieraj, 2012).

It should be noted that the problem of the logwall crew selection was a subject of research and analytical studies practically from the moment when longwall system had been used in hard coal mines. The method described in the present study takes under consideration a new factor, which was not used before, i.e. stochastic character of the process realized in the longwall face (Sukiennik, 2011).

Detailed description of the method in question is given in the first part of this study (Snopkowski & Sukiennik, 2012). A computational example, in which crew was determined for conditions of specific longwall face is also presented.

2. Example of the crew selection in case of the production process based on the developed method

The example was elaborated on the basis of data obtained from the longwall face with roof cut and fill mining system, which is characterized in Table 1.

TABLE 1

Longwall face characteristics

Basic parameters	Hazards	Equipment
Longwall lenght 220 [m] Longwall height 4,2 [m] Maximal web 0,8 [m] Longitudinal longwall inclination 2 [°] Direct roof 0-6,2 [m] clay slate Basal roof 37,7-43,2 [m] sandstones Seam floor 1,5-2,4 [m] clay slate	Dusty class. A Fire group V Water I-st degree	Shearer KSW-2000E Conveyor RYBNIK 1100 Conveyor GROT 1100 Support FAZOS-22/45-POz

Source: the authors material

2.1. Characteristics of the production process

Characteristics of the production process realized in the longwall face is presented below and its description is show in Table 1.

2.1.1. Process structure

Production process realized in the tested longwall face comprises production cycle and activities and operations related with technological cycle. Production cycle was realized with use of the shearer two way cutting technology. Scheme of this cycle with isolated and suitably marked module, which will constitute basis of further calculations, is shown in Fig 1.

The other data listed in the figure had the following values:

$x_1 = 13$ [m]; $x_2 = 3$ [m]; $x_3 = 16$ [m]; $x_p = 22$ [m]; $L = 222$ [m].

In scope of the operations related with technological cycle, which are show in Fig. 2, the longwall face crew will be selected. These operations are related with crossing rebuilding and correction of conveyors location according to the longwall advance.

Function used for description of activities (operations) executed within individual modules from 1 to 7 are characterized in next parts of this study.

2.1.2. Density functions

On the basis of chronometer examinations executed in conditions of given longwall face, density functions describing times of the activities and operations realization on distance of 1 meter have been taken for the calculations. Function characteristics is presented in Table 2.

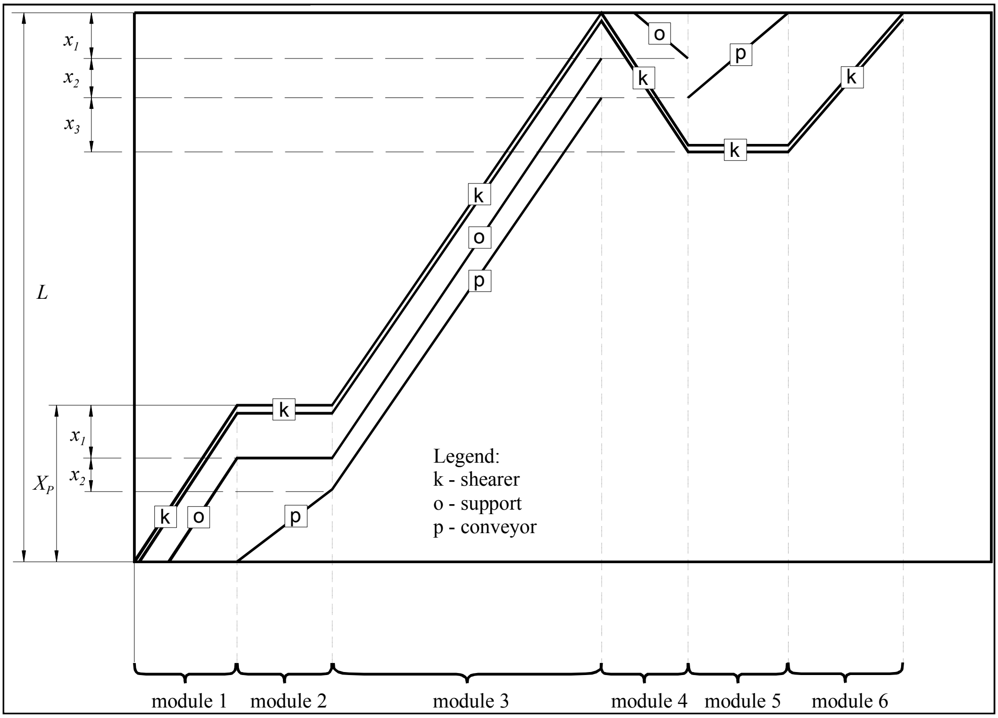

Fig. 1. Scheme of the production cycle for two way shearer mining with isolated modules
Source: (Snopkowski, 1997) with modifications

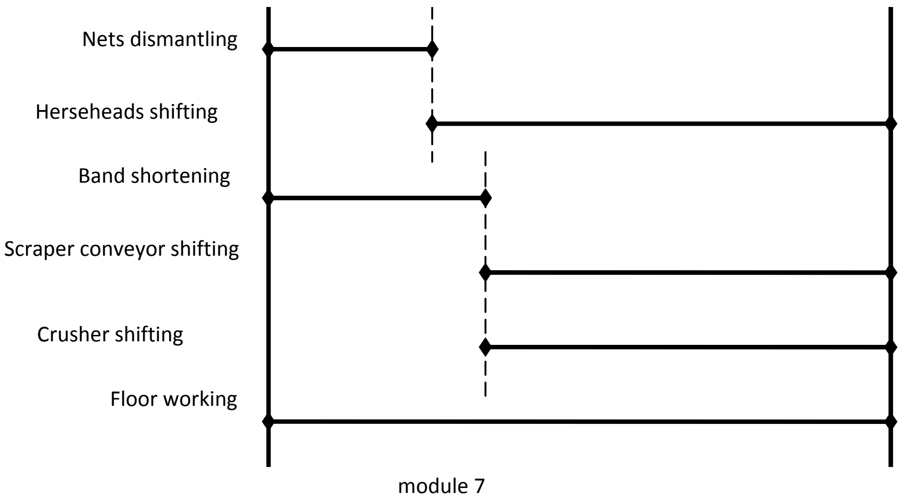

Fig. 2. Scheme of Works executed in scope of the technological cycle
Source: Author's materials

TABLE 2

Characteristics of density functions used in calculations

Name of activity or operation	Crew	Density function	Parameters of density function
Working with use of shearer	2	beta	$\alpha = 2{,}3$; $\beta = 2{,}1$; $A = 0{,}1$; $B = 0{,}6$
Cleaning with use of shearer	2	beta	$\alpha = 2{,}3$; $\beta = 4{,}2$; $A = 0{,}1$; $B = 0{,}5$
Slatting with used of shearer	2	beta	$\alpha = 4{,}5$; $\beta = 2{,}1$; $A = 0{,}1$; $B = 0{,}75$
Support shifting	1 2 3	beta beta beta	$\alpha = 2{,}1$; $\beta = 2{,}9$; $A = 0{,}1$; $B = 0{,}85$ $\alpha = 2{,}0$; $\beta = 3{,}6$; $A = 0{,}1$; $B = 0{,}85$ $\alpha = 2{,}2$; $\beta = 4{,}4$; $A = 0{,}1$; $B = 0{,}85$
Conveyor shifting	1 2 3	normal normal normal	$\mu = 0{,}42$; $\delta = 0{,}12$ $\mu = 0{,}38$; $\delta = 0{,}07$ $\mu = 0{,}32$; $\delta = 0{,}15$
Driving unit shifting	6	normal	$\mu = 18$; $\delta = 2$
Turning station shifting	6	normal	$\mu = 15$; $\delta = 1{,}5$
Nets dismantling	1 2	gamma gamma	$\alpha = 25$; $\lambda = 1$ $\alpha = 21$; $\lambda = 1$
Horseheads shifting	2	gamma	$\alpha = 15$; $\lambda = 1$
Band shortening	2	gamma	$\alpha = 12$; $\lambda = 1$
Scraper conveyors shifting	2 4	gamma gamma	$\alpha = 39$; $\lambda = 1$ $\alpha = 20$; $\lambda = 1$
Crusher shifting	2	gamma	$\alpha = 25$; $\lambda = 1$
Floor working	1	normal	$\mu = 35$; $\delta = 5$

Source: Authors materials

2.2. Crew calculation in individual modules

Calculations executed in order to select production process crew were executed for each module. Procedure of calculations executed for each module is as follow:

Module 1

This module comprises operations of cleaning with use of shearer on distance of 22 m. Shifting of the support on a distance of 9 m is made during realization of this operation. Shearer cleaning is considered as leading operation thus algorithm described in work by Snopkowski, Sukiennik, 2012 was used in the calculations.

On a distance of 22 m, a convolution function was determined with use of central boundary theorem. The obtained function is considered as normal distribution with parameters: $\bar{x} = 5{,}29$; $\sigma = 0{,}33$. Value t_0 was calculated with use of integral:

$$\int_{-\infty}^{t^0} \frac{1}{0{,}33\sqrt{2\pi}} \cdot e^{\frac{-(x-5{,}29)^2}{2\cdot 0{,}33^2}} dx = p \tag{1}$$

Under assumption that $p = 0{,}95$, value t_0, which satisfies the above equation amounts for 5,83.

The next procedural step comprised calculation of the function describing support shifting on a distance of 9 m. This function was determined for crew limited to 1 worker. Convolution function was determined via simulation with use of central boundary theorem. Obtained function is considered as normal distribution with parameter $\overline{x} = 3{,}9$; $\sigma = 0{,}44$. In order to calculate probability that support shifting will be shorter than shearer clearing, the following integral should be calculated:

$$\int_{-\infty}^{5,8} \frac{1}{0{,}44\sqrt{2\pi}} \cdot e^{\frac{-(x-3{,}9)^2}{2 \cdot 0{,}44^2}} dx = 0{,}99 \tag{2}$$

The calculated probability exceeds value 0,95 what means that we should assume support shifting crew on distance of 9 m on the level of 1 worker.

Module 2

In the second module, driving unit shifting, conveyor shifting on distance of 6 m and shearer standstill take place. Driving unit shifting is a leading operation. Normal distribution of parameters $\overline{x} = 18$; $\sigma = 2$, is a function describing this operations. In order to determine value t_0, the following integral was calculated:

$$\int_{-\infty}^{t^0} \frac{1}{2\sqrt{2\pi}} \cdot e^{\frac{-(x-18)^2}{8}} dx = p \tag{3}$$

Under Assumption that p = 0,95, value t_0, satisfying the above equation amounts for 21,30.

The next procedural step comprises calculation of the function describing activity of conveyor shifting on a distance of 6 m. This function was determined for the crew limited to 1 worker.

The following theorem was used:

If X_1; X_2;... X_r, are independent random variables of normal distribution with parameters: $\overline{x}_1, \sigma_1$; $\overline{x}_2, \sigma_2$; ... $\overline{x}_r, \sigma_r$, the random variable $X_1 + X_2 + \ldots + X_r$ has also normal distribution with parameters: $\overline{x} = \overline{x}_1 + \overline{x}_2 + \ldots + \overline{x}_r$ and $\sigma = \sqrt{\sigma_1^2 + \sigma_2^2 + \ldots + \sigma_r^2}$.

Thus calculated function has form of normal distribution with parameters $\overline{x} = 2{,}52$; $\sigma = 0{,}29$. Probability that conveyor shifting will take shorter time than turning station shifting, the following integral was calculated:

$$\int_{-\infty}^{21,30} \frac{1}{0{,}29\sqrt{2\pi}} \cdot e^{\frac{-(x-2{,}52)^2}{2 \cdot 0{,}29^2}} dx = 1{,}0 \tag{4}$$

Calculated probability exceeds value 0,95, what means that the crew for operations of conveyor shifting on a distance of 9 m should be selected on the level of 1 worker (conveyor shifting will not take longer time than driving unit shifting). The shearer standstill takes the same time as the driving unit shifting.

Module 3

Three operations are executed in this module: shearer working, conveyor shifting and support shifting. All these operations are executed on a distance of 200 m. Shearer working is considered as leading operation. The other operations, i.e. support and conveyor shifting should not stop the shearer advance. Beta distribution with parameters: $\alpha = 2{,}3$; $\beta = 2{,}1$; $A = 0{,}1$; $B = 0{,}6$ is considered as the function describing the operations. Taking under consideration the central boundary theorem, normal distribution with parameters $\bar{x} = 72{,}26$; $\sigma = 1{,}68$, describing the shearer working on a distance of 200 m, was obtained. Value t_0 was determined from the following relation:

$$\int_{-\infty}^{t^0} \frac{1}{1{,}68\sqrt{2\pi}} \cdot e^{\frac{-(x-72{,}26)^2}{2\cdot 1{,}68^2}} dx = p \tag{5}$$

Under assumption that $p = 0{,}95$, is value t_0, which satisfies the above equation amounts for 75,02. Crew selection for other operations allowing time of their execution shorter than 75,02 at the probability level of at least 0,95 will be determined in further calculations.

Calculations for operations „support shifting”

Variant I: 1 worker crew

Taking under consideration central boundary theorem, form of the function describing time of the support shifting on a distance of 200 m is as follow:

$$f(x) = \frac{1}{6{,}01\sqrt{2\pi}} \cdot e^{\frac{-(x-82{,}99)^2}{2\cdot 6{,}01^2}} \tag{6}$$

It is normal distribution with parameters $\bar{x} = 82{,}99$; $\sigma = 6{,}01$. In order to calculate probability that support shifting will take shorter time than executed in the same time activity “shearer working”, the following probability is determined:

$$\int_{-\infty}^{75{,}02} \frac{1}{6{,}01\sqrt{2\pi}} \cdot e^{\frac{-(x-82{,}99)^2}{2\cdot 6{,}01^2}} dx = 0{,}09 \tag{7}$$

This probability is very low what means that in case of 1 worker crew the support shifting will stop shearer working.

Variant II: 2 workers crew.

Taking under consideration the central boundary theorem, the function describing the support shifting on a distance of 200 m was determined. This function has following form:

$$f(x) = \frac{1}{2{,}16\sqrt{2\pi}} \cdot e^{\frac{-(x-73{,}57)^2}{2\cdot 2{,}16^2}} \tag{8}$$

It is normal distribution with parameters $\bar{x} = 73{,}57$; $\sigma = 2{,}16$. In order to calculate probability that support shifting will take shorter time than executed in the same time activity „shearer working”, an integral should be calculated:

$$\int_{-\infty}^{75{,}02} \frac{1}{2{,}16\sqrt{2\pi}} \cdot e^{\frac{-(x-73{,}57)^2}{2\cdot 2{,}16^2}} dx = 0{,}75 \tag{9}$$

Calculated probability do not exceed assumed value of 0,95, Thus 2 workers crew also do not assure that shearer is not stopped because of too slow shifting of mechanical support.

Variant III: 3 workers crew.

Taking under consideration the central boundary theorem, function describing the support shifting on a distance of 200 m by 3 workers has form:

$$f(x) = \frac{1}{1{,}98\sqrt{2\pi}} \cdot e^{\frac{-(x-70{,}00)^2}{2 \cdot 1{,}98^2}} \tag{10}$$

It is normal distribution with parameters $\bar{x} = 70{,}00$; $\sigma = 1{,}98$. In order to calculate probability that the support shifting will take shorter time than shearer working, it was calculated::

$$\int_{-\infty}^{75{,}02} \frac{1}{1{,}98\sqrt{2\pi}} \cdot e^{\frac{-(x-70{,}00)^2}{2 \cdot 1{,}98^2}} dx = 0{,}99 \tag{11}$$

It should be concluded on the basis of calculated probability that 3 workers will assure proper rate of the support shifting with reference to working shearer.

<u>Calculation of operations „conveyor shifting"</u>

Variant I: 1 worker crew.

Taking under consideration theorem of the sum of independent variables in normal distributions, a function describing conveyor shifting on a distance of 200 m by 1 worker was determined:

$$f(x) = \frac{1}{1{,}7\sqrt{2\pi}} \cdot e^{\frac{-(x-84)^2}{2 \cdot 1{,}7^2}} \tag{12}$$

It is normal distribution with parameters $\bar{x} = 84$; $\sigma = 1{,}7$. In order to calculate probability that conveyor shifting will take sorter time than shearer working, the following was calculated:

$$\int_{-\infty}^{75{,}02} \frac{1}{1{,}7\sqrt{2\pi}} \cdot e^{\frac{-(x-84)^2}{2 \cdot 1{,}7^2}} dx = 6{,}37 \cdot 10^{-8} \tag{13}$$

Calculated probability is very small what means that the conveyor shifting will be realized too slow.

Variant II: 2 workers crew.

Taking under consideration theorem of the sum of independent variables in normal distributions, a function describing conveyor shifting on a distance of 200 m by 2 workers was determined:

$$f(x) = \frac{1}{0{,}99\sqrt{2\pi}} \cdot e^{\frac{-(x-76)^2}{2 \cdot 0{,}99^2}} \tag{14}$$

It is normal distribution with parameters $\overline{x} = 76$; $\sigma = 0{,}99$. In order to calculate probability that the conveyor shifting will take sorter time than shearer working, the following was calculated:

$$\int_{-\infty}^{75{,}02} \frac{1}{0{,}99\sqrt{2\pi}} \cdot e^{\frac{-(x-76)^2}{2\cdot 0{,}99^2}} dx = 0{,}16 \tag{15}$$

Calculated probability has value 0,16, what means that conveyor shifting realized by two workers will be too slow as compared with shearer working.

Variant III: 3 workers crew.

Taking under consideration theorem of the sum of independent variables in normal distributions, a function describing conveyor shifting on a distance of 200 m by 3 workers was determined:

$$f(x) = \frac{1}{2{,}12\sqrt{2\pi}} \cdot e^{\frac{-(x-64)^2}{2\cdot 2{,}12^2}} \tag{16}$$

It is normal distribution with parameters $\overline{x} = 64$; $\sigma = 2{,}12$. In order to calculate probability that the conveyor shifting will take shorter time than shearer working it calculated from the following relation:

$$\int_{-\infty}^{75{,}02} \frac{1}{2{,}12\sqrt{2\pi}} \cdot e^{\frac{-(x-64)^2}{2\cdot 2{,}12^2}} dx = 0{,}99 \tag{17}$$

Calculated probability indicates that the crew on 3 workers level is proper for conveyor shifting on a distance of 200 m.

Module 4

This module comprises operations of the shearer slotting and the support shifting on a distance of 13 m. Shearer slotting is considered as leading operation. Method of the function convolution via simulation with use of the central boundary theorem was applied in order to obtain function describing the shearer slotting time on a distance of 32 m. Obtained function is considered as normal distribution with parameters: $\overline{x} = 17{,}99$; $\sigma = 0{,}75$. Value t_0 was obtained from the following relation:

$$\int_{-\infty}^{t^0} \frac{1}{0{,}75\sqrt{2\pi}} \cdot e^{\frac{-(x-17{,}99)^2}{2\cdot 0{,}75^2}} dx = p \tag{18}$$

Under assumption that $p = 0{,}95$, value t_0, which satisfied this equation, amounts for 19,22. Thus the support shifting on a distance of 13 m should be executed in sorter time than 19,22 (on assumed probability level 0,95). Taking under consideration the central boundary theorem, the function describing conveyor shifting time by 1 worker on a distance 13 m has the following form:

$$f(x)=\frac{1}{0{,}56\sqrt{2\pi}}\cdot e^{\frac{-(x-5{,}43)^2}{2\cdot 0{,}56^2}} \tag{19}$$

It is normal distribution with parameters $\bar{x}$ = 5,43; σ = 0,56. In order to calculate probability that the support shifting will take sorter time than the shearer slotting shifting will take shorter time than the shearer slotting, the following should be calculated:

$$\int_{-\infty}^{19{,}22}\frac{1}{0{,}56\sqrt{2\pi}}\cdot e^{\frac{-(x-5{,}43)^2}{2\cdot 0{,}56^2}}dx=1{,}0 \tag{20}$$

On the basis of calculated probability 1 worker crew should be selected for the operations of the support shifting on a distance of 13 m.

Module 5

This module comprises operations of the conveyor and turning station shifting on a distance of 16 m. Turning station shifting is accompanied with the shearer stoppage for a time period, which is identical as the time of the turning station shifting. Turning station is considered as leading operation. This operation is described by function being a normal distribution of parameters: $\bar{x}$ = 15; σ = 1,5. Value t_0 was determined by calculation of the following integral:

$$\int_{-\infty}^{t^0}\frac{1}{1{,}5\sqrt{2\pi}}\cdot e^{\frac{-(x-15)^2}{2\cdot 1{,}5^2}}dx=p \tag{21}$$

Under assumption that p = 0,95, value t_0, which satisfied the above equation, amounts for 17,47. Next procedural step comprises deriving a function describing the conveyor shifting on a distance of 16 m. Taking under consideration theorem about the sum of independent random variables with normal distribution, a function describing the conveyor shifting on a distance of 16 m by 1 worker was determined:

$$f(x)=\frac{1}{0{,}48\sqrt{2\pi}}\cdot e^{\frac{-(x-6{,}72)^2}{2\cdot 0{,}48^2}} \tag{22}$$

It is normal distribution with parameters $\bar{x}$ = 6,72; σ = 0,48. In order to calculate probability that the conveyor shifting will take sorter time than the turning station shifting it was calculated that:

$$\int_{-\infty}^{17{,}47}\frac{1}{0{,}48\sqrt{2\pi}}\cdot e^{\frac{-(x-6{,}72)^2}{2\cdot 0{,}48^2}}dx=1{,}0 \tag{23}$$

On the basis of calculated probability, an operations crew at the level of 1 worker for the conveyor shifting should be selected.

Module 6

In module marked with number 6, operations of the shearer working on the distance of 32 m is executed. No other operations are predicted during execution of this operations. It means that in the module 6 the crew is the same as in shearer working operation. The crew comprises shearer operator and his assistant, thus it is 2 persons crew.

Module 7

Operations realized within technological cycle are executed in module 7. Structure of these operations is shown in Fig 2. Procedure of the crew selection in module 7 was conducted according to an algorithm, which is described in the first part of the study (Snopkowski & Sukiennik, 2012).

The first step in the crew selection algorithm comprises so called full paths. Full paths for module marked with number 7 are distinguished in Table 3.

TABLE 3

Full paths in module 7

Path symbol	Operations of the full path
S_1	Nets dismantling + horsehead shifting
S_2	Band shortening + scraper conveyor shifting
	Band shortening + crusher shifting
S_4	Floor working

Source: The authors study

For each full path, taking under consideration suitable variant of crew selection, functions describing duration of given activity was determined. Analytical form of these functions and results of executed calculations are shown in Table 4.

Symbols of the variant and module selection are shown in the first table column, whereas name of operations is cited in the second column and values of assumed size of the selected crew is shown in the third column. Total crew size of the module in scope of given variant is shown in the forth column. Functions describing duration of full paths for given variant of the crew selection are shown in fifth column, and calculated on assumed level probabilities (0,95) durations of individual full paths are shown in sixth column. Calculated durations of whole module 7 for assumed screw selection variants from W_{I} do W_{IV} are shown in the last column of Table 4.

W_{IV} is considered as variant assuring optimally short realization of module 7, which crew is composed of 13 workers. Duration of the module for this variant amounts for 47,54 [min].

Interpretation of the executed calculations in shown in Fig. 3.

The longwall face crew selected on the basis of the method proposed in this study for a case of two way shearer mining technology assure continuous realization of the production process in the longwall face, in option of minimized numbers of workers.

As seen in Fig 3, each of the activities of the production process has prescribed optimal crew variant. The crew of the whole production process is determined via assigning concrete workers to individual activities, taking under consideration that some activities can be executed by the same workers. It can be also assumed, that some modules can be realized by the same crew groups, under condition that there is no time conflict between these groups.

TABLE 4

Calculation results for module 7

Symbol wariantu obsady modułu	Nazwa operacji	Przyjęta w wariancie obsada operacji	Obsada modułu dla wariantu W_i [prac.]	Funkcje opisujące czas trwania ścieżek pełnych dla danego wariantu obsady	$t_0^{S,W}$	Czas trwania modułu dla danego wariantu obsady
W_{I}	Nets dismantling	1	10	$f^{S_1 W_{I}} \rightarrow$ gamma $(\alpha = 40; \lambda = 1)$	50,94	$t_0^{W_{I}} = 63{,}29$
	Househeads shifting	2		$f^{S_2 W_{I}} \rightarrow$ gamma $(\alpha = 51; \lambda = 1)$	63,29	
	Band shortening	2		$f^{S_3 W_{I}} \rightarrow$ gamma $(\alpha = 37; \lambda = 1)$	47,54	
	Scraper conveyor shifting	2		$f^{S_4 W_{I}} \rightarrow$ normal $(\bar{x} = 40; \sigma = 5)$	43,22	
	Crusher shifting	2				
	Floor working	1				
W_{II}	Nets dismantling	1	12	$f^{S_1 W_{II}} \rightarrow$ gamma $(\alpha = 40; \lambda = 1)$	50,94	$t_0^{W_{II}} = 50{,}94$
	Househeads shifting	2		$f^{S_2 W_{II}} \rightarrow$ gamma $(\alpha = 32; \lambda = 1)$	41,84	
	Band shortening	2		$f^{S_3 W_{II}} \rightarrow$ gamma $(\alpha = 37; \lambda = 1)$	47,54	
	Scraper conveyor shifting	4		$f^{S_4 W_{II}} \rightarrow$ normal $(\bar{x} = 35; \sigma = 5)$	43,22	
	Crusher shifting	2				
	Floor working	1				
W_{III}	Nets dismantling	2	11	$f^{S_1 W_{III}} \rightarrow$ gamma $(\alpha = 36; \lambda = 1)$	46,40	$t_0^{W_{III}} = 63{,}29$
	Househeads shifting	2		$f^{S_2 W_{III}} \rightarrow$ gamma $(\alpha = 51; \lambda = 1)$	63,29	
	Band shortening	2		$f^{S_3 W_{III}} \rightarrow$ gamma $(\alpha = 37; \lambda = 1)$	47,54	
	Scraper conveyor shifting	2		$f^{S_4 W_{III}} \rightarrow$ normal $(\bar{x} = 35; \sigma = 5)$	43,22	
	Crusher shifting	2				
	Floor working	1				
W_{IV}	Nets dismantling	2	13	$f^{S_1 W_{IV}} \rightarrow$ gamma $(\alpha = 36; \lambda = 1)$	46,40	$t_0^{W_{IV}} = 47{,}54$
	Househeads shifting	2		$f^{S_2 W_{IV}} \rightarrow$ gamma $(\alpha = 32; \lambda = 1)$	41,84	
	Band shortening	2		$f^{S_3 W_{IV}} \rightarrow$ gamma $(\alpha = 37; \lambda = 1)$	47,54	
	Scraper conveyor shifting	4		$f^{S_4 W_{IV}} \rightarrow$ normal $(\bar{x} = 35; \sigma = 5)$	43,22	
	Crusher shifting	2				
	Floor working	1				

Source: Author’s materials2.3. Production process crew selecting detrmined on the basis of the developed method

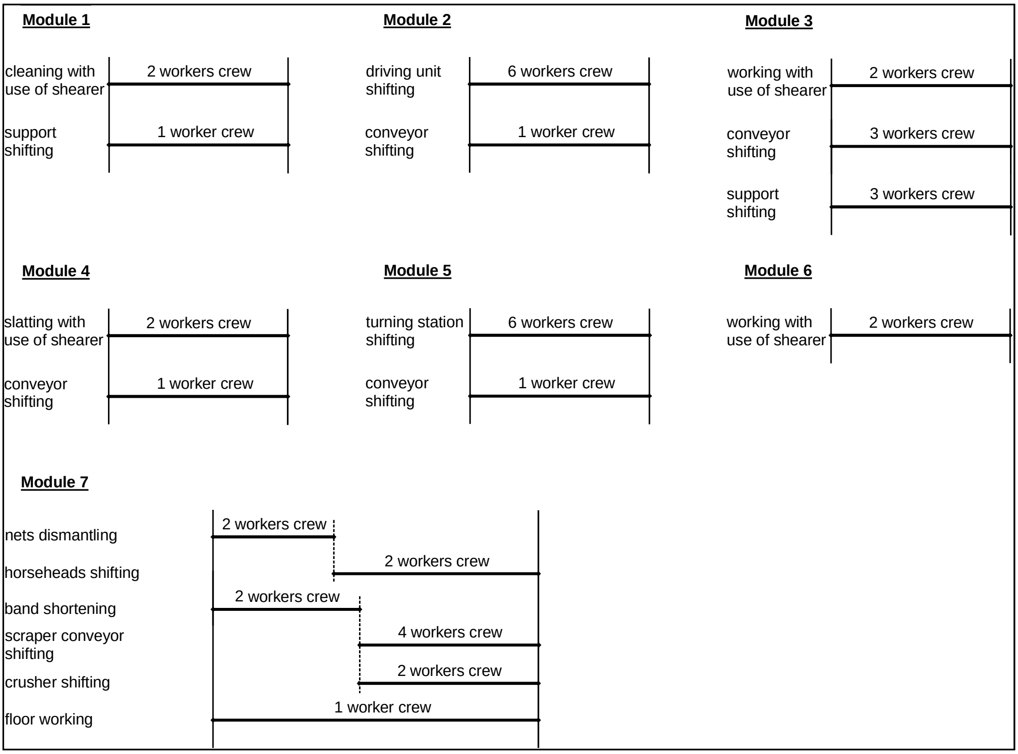

Fig. 3. Scheme of the production cycle crew in chosen longwall face
Source: Author's materials

3. Final conclusions

Observations of the activity or operation durations confirm thesis that these times are exposed to fluctuations, which can result from geological and mining conditions.

The proposed method assumes application of the density probability functions of the activity durations in selection of the longwall face crew. Different than deterministic attitude was used, and activity duration was considered as random variable. Replacement of deterministic variables with random ones, in form of density probability functions, allowed taking under consideration numerous factors influencing the activity duration.

It can be concluded that (Snopkowski & Sukiennik, 2012):

1. Each production process can be divided into finite number of modules differing with the activity synchronism realization.
2. Isolation of module from production process allows easy analysis of the production process, i.e. facilitates the crew selection.
3. The used criterion of the probability of reaching assumed duration of the module realization allow rational selection of the longwall face crew, as the realization of the module as a whole has higher priority than realization of individual activities.

Developed method of the longwall face crew selection can be used in practice, particularly in such longwall faces of hard coal mines, which are mined in conditions influencing their stochastic character, which has been described in the present study.

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