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SELECTION OF THE LONGWALL FACE CREW WITH RESPECT TO STOCHASTIC CHARACTER OF THE PRODUCTION PROCESS – PART 1 – PROCEDURAL DESCRIPTION

WYZNACZANIE OBSADY PRZODKA ŚCIANOWEGO Z UWZGLĘDNIENIEM STOCHASTYCZNEGO CHARAKTERU PROCESU PRODUKCYJNEGO. CZ. 1 – OPIS METODY

A proposal of the method aimed at the longwall face crew selection with respect to stochastic character of the production process has been described in this study. Modules, which can be isolated from the production cycle, as well as methods of determination of the probability function density describing duration of individual action realized in production process, have been described in the first part of the study.

Procedure of crew selection of individual modules, including optional crew selection, has been described in next chapters. Statement of action, which should be executed in order to apply the proposed method, including final conclusions, is discussed in the last chapter.

Keywords: longwall face crew selection, probability function density, 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.

Pierwszym krokiem w proponowanej metodzie jest podział procesu produkcyjnego na moduły. Kryterium podziału stanowi sposób realizacji poszczególnych czynności lub operacji w danym module. Zaproponowano cztery rodzaje modułów i oznaczono odpowiednio literami od A do D.

Moduły typu A to moduły z czynnościami wykonywanymi w sposób równoległy, wśród których występuje tzw. czynność wiodąca. Czynność wiodąca jest to taka czynność, której realizacja nie powinna być wstrzymywana z powodu zbyt wolnego wykonywania pozostałych czynności występujących w tym module. Moduły typu B to takie, w których czynności lub operacje wykonywane są w sposób równoległy, ale wśród niech nie występuje czynność wiodąca. Czynności wykonywane w sposób szeregowy

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charakteryzują moduły typu C. W modułach tych może być wykonywana dowolna ilość czynności w układzie szeregowym, dodatkowo czynność pojedynczą traktuje się jak szeregową. Moduły typu A, B i C wyodrębnione są z cyklu produkcyjnego na rysunku 1.

Cechą charakterystyczną modułów typu D jest występowanie czynności lub operacji zarówno w układzie równoległym, jak i szeregowym. Na rysunku 2 zamieszczono przykład takiego modułu.

Kolejnym krokiem w metodzie wyznaczania obsady przodka ścianowego jest wyznaczenie funkcji gęstości prawdopodobieństwa, opisujących czas realizacji poszczególnych czynności w ramach wyodrębnionych modułów. Schemat wyznaczania funkcji opisujących czas trwania czynności lub operacji w ramach modułów zamieszczono na rysunku 3. Przestawiony schemat zakłada zebranie danych pomiarowych a następnie przeprowadzenie analizy statystycznej, która polega na wyznaczeniu funkcji aproksymujących $f_{1,i,j}$, mających własności funkcji gęstości prawdopodobieństwa. Funkcje te opisują czas realizacji czynności lub operacji „i"-tej wykonywanej w ramach danego modułu „j"-tego, na odcinku jednego metra. Następnie wyznacza się splot otrzymanych funkcji w celu wyznaczenia funkcji splotowych $\mathrm{f}_{\mathrm{i,j}}$, które opisują czas realizacji czynności lub operacji „i"-tej w danym module „j"-tym. Otrzymane funkcje splotowe mają własności funkcji gęstości prawdopodobieństwa. Można je wyznaczyć dwiema metodami: metodą analityczną lub metodą symulacyjną. W metodzie analitycznej wykorzystuje się definicję splotu funkcji, natomiast w metodzie symulacyjnej schemat postępowania, który zamieszczono na rysunku 4.

Jeżeli w module znajdują się czynności lub operacje, które mogą być wykonywane przez różną liczbę pracowników (obsadę), wówczas funkcja $f_{i,j}$ wyznaczana jest dla każdego wariantu obsady z osobna. Symbolem „k" oznaczono obsadę, dla której funkcja $f_{i,j}$ została wyznaczona.

Po wyznaczeniu funkcji gęstości prawdopodobieństwa, opisujących czas realizacji poszczególnych czynności, następuje wyznaczenie obsady w ramach poszczególnych modułów. W związku z wydzieleniem trzech typów modułów przedstawiono algorytmy wyznaczania obsady uwzględniające to zróżnicowanie.

Algorytm wyznaczania obsady dla modułów z czynnościami lub operacjami równoległymi i wiodącymi przedstawiony jest w rozdziale 4.1. Na rysunku 5 zamieszczono przykład modułu, w którym występuje czynność wiodąca a następnie z wykorzystaniem wzorów od 1 do 4 opisano procedurę postępowania przy wyznaczaniu obsady w modułach typu A.

Algorytm wyznaczania obsady dla modułów z czynnościami lub operacjami równoległymi bez wiodących opisano w rozdziale 4.2. Na rysunku 6 zmieszczono przykładowy moduł z dwiema czynnościami równoległymi, z których żadna nie jest wiodącą. Wzorami od 5 do 10 opisano procedurę wyznaczania obsady w modułach typu B.

Moduły typu C oraz schemat wyznaczania obsady opisane są w rozdziale 4.3. Rysunek 7 prezentuje przykładowy moduł z dwiema czynnościami szeregowymi, a wzory od 11 do 15 przedstawiają proces wyznaczania obsady w modułach tego typu.

Algorytm wyznaczania obsady dla modułów z czynnościami lub operacjami wykonywanymi szeregowo i równolegle zaprezentowany jest w rozdziale 4.4. Na rysunku 8 zamieszczono przykładowy moduł, a wzory od 16 do 26 prezentują procedurę wyznaczania obsady w modułach typu D.

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.

Zastosowanie opracowanej metody wymaga realizacji szeregu czynności, z których najważniejsze to:

– identyfikacja kluczowych czynności w procesie produkcyjnym,
– podział procesu produkcyjnego na charakterystyczne moduły, ze względu na jednoczesność realizacji czynności,
– identyfikacja funkcji gęstości czasów trwania czynności w wydzielonych modułach,
– przyjęcie wstępnych wariantów obsady dla poszczególnych modułów
– optymalizacja obsady w modułach poprzez uwzględnienie prawdopodobieństw realizacji czynności przy założonej obsadzie z uwzględnieniem charakteru modułów.

Można także zauważyć, ze:

1. Każdy proces produkcyjny można podzielić na skończoną liczbę modułów różniących się jednoczesnością realizacji czynności.
2. Wyodrębnianie z procesu produkcyjnego modułów, pozwala na łatwiejszą analizę procesu produkcyjnego, a co za tym idzie ułatwia dobór obsady.

3. Użyte w metodzie kryterium prawdopodobieństwa osiągnięcia założonego czasu trwania realizacji modułu, pozwala na racjonalny dobór obsady, gdyż realizacja modułu jako całości ma wyższy priorytet niż realizacja poszczególnych czynności.

Słowa kluczowe: obsada przodka ścianowego, funkcje gęstości prawdopodobieństwa, cykl produkcyjny, przodek ścianowy

1. Introduction

Studies aimed at the analysis of longwall face operations with respect to stochastic character of the production process were started in the nineties of the last century (Snopkowski, 1990, 1994). Studies aimed at the analysis of production of coal excavated from longwall faces with respect to chosen probability distributions were continued in the next decades (Snopkowski, 2000a, 2000b, 2002). Stochastic simulation method was used as the research method (Snopkowski, 2005, 2007a, 2007b, 2009) and (Snopkowski & Napieraj, 2012).

Thus the problem of the longwall face crew selection was started at the same time as longwall exploitation system was applied in hard coal mines. However, the method described in the present study takes under consideration not considered so far factor, i.e. stochastic character of the process realized in the longwall face (Sukiennik, 2011).

Division of the production process into modules is the first procedural step of the method of question. Manner of the realization of individual activities or operations in given module is considered as a criterion of this division.

2. Division of the production process into modules

In the production process realised within the longwall face of hard coal mines we can isolate its smaller fragments, which are determined as "modules" in the present study. Such partition is aimed at development of the crew selection method, which takes under consideration different character of these modules. The modules differ from each other with manner of realization of individual activities or operations. Detail information related with procedure of defining particular modules are described in next chapters of this study.

2.1. Modules comprising activities or operations executed in parallel

To this group of the production process are prescribed activities or operations, which are executed in parallel. Modules with co called leading activities and modules without such activities can be distinguished.

Modules with leading activities or operations are characterized with two features. The first feature comprises parallelism of the executed activities or operations and the second one is characterized with presence of so called leading activity. Example of the module of this type marked with symbol "A" is shown in Fig. 1.

Module marked with symbol „A" comprises fragment of the production cycle, in which shearer cuts coal rock body and is followed by support and conveyor shifting, which are moved toward the longwall face. Shearer cutting is considered as leading activity in this module. This activity determinates two other activities. In practice it means that the shearer shouldn't wait for the support or conveyor shift. Thus shearer standstill on the section ($L-X_p$) shouldn't take place because it could result in daily output decrease. Module of type „A" occur anywhere where fragments of the parallel activities or operations are present, in which single activity is considered as leading activity.

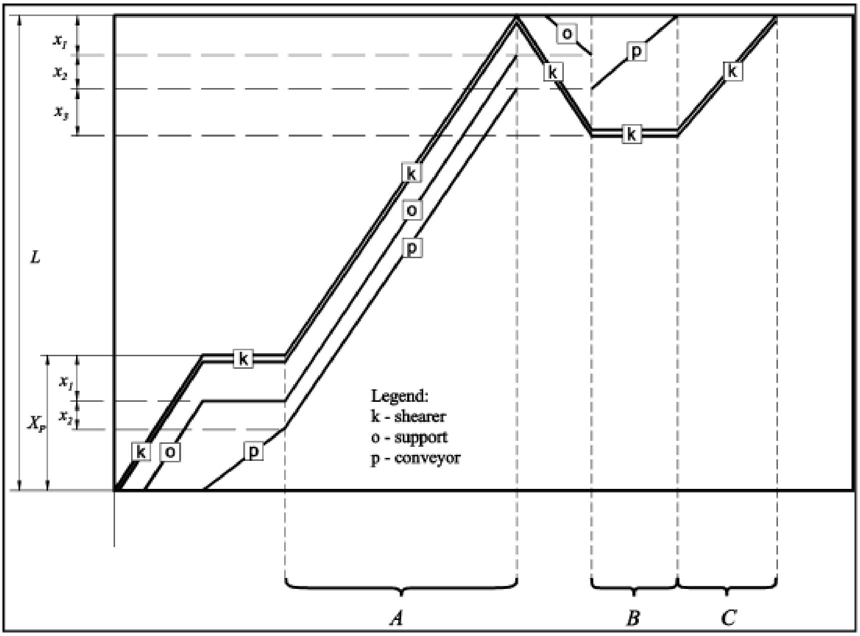

Fig. 1. Scheme of the production cycle for two way shearer mining with isolated modules.
Source: (Snopkowski, 1997) with modifications

Parallelism and lack of leading activity or operations is a characteristic feature of module without leading activities or operations. Example of the module of this type marked as "B" s shown in Fig. 1. Operation of the drive unit shift when the shearer is stopped in a distance ($x_1 + x_2 + x_3$) from the driver unit occurs in this module. Shearer is exposed to short maintenance with eventual replace of cutting picks. It should be noted that in case of other mining processes we can also isolate modules, which in Fig. 1 are marked as „A" and „B".

2.2. Modules with activities and operations executed in series

Lack of activities and operations executed in parallel is the most important feature of the module of this type, which can be isolated fro production process. Example of the module of this type marked as „C" is shown in Fig. 1. This is shearer advance, during which no other activities or operations are executed. In case of several operations executed in series, the operations are classified as the operations of the same module.

2.3. Modules and operations executed in series and in parallel

Occurrence of activities or operations both in parallel and in series system is a characteristic feature of the module of this type. Example of such module is shown in Fig. 2.

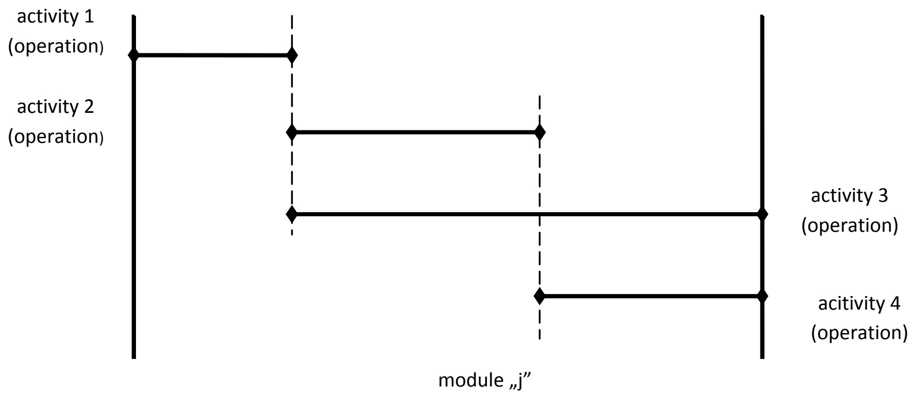

Fig. 2. Example of module of the type D with activities or operations executed In series and in parallel. *Source:* Authors materials

In this module occur both activities (operations) executed in the in series, i.e. marked with sequent digits 1,2 and 4, and also 1 and 3, and parallel system comprising activities (operations) 2,3 and 4.

3. Developing the functions describing activity or operation duration executed within the modules

Scheme of the development of functions describing duration of activities and operations within individual modules is shown in Fig. 3.

Realization of the scheme presented in Fig. 3 is preceded by collection of suitable data in conditions of concrete longwall face. For example, for a module marked as "*A*" in Fig. 1, the data comprise shearer operational speed, support advance rate and conveyor shifting rate. Then the data are exposed to statistical analysis comprising determination of approximation functions $f_{1,i,j}$, having properties characteristic for probability density function. These functions describe time of realization of "*i*" activity or operation in scope of given "*j*" module on a distance of 1 meter.

Next procedural step shown in the scheme comprises development of obtained convolution in order to determine convolution functions $f_{i,j}$, which describe time of realization of "i" activity or operation within "*j*" module. Obtained convolution functions have properties characteristic for probability density functions. They can be determined with use of two methods: analytical method or simulation method.

Definition of convolution function is used in analytical method and the procedural scheme is shown in Fig. 4.

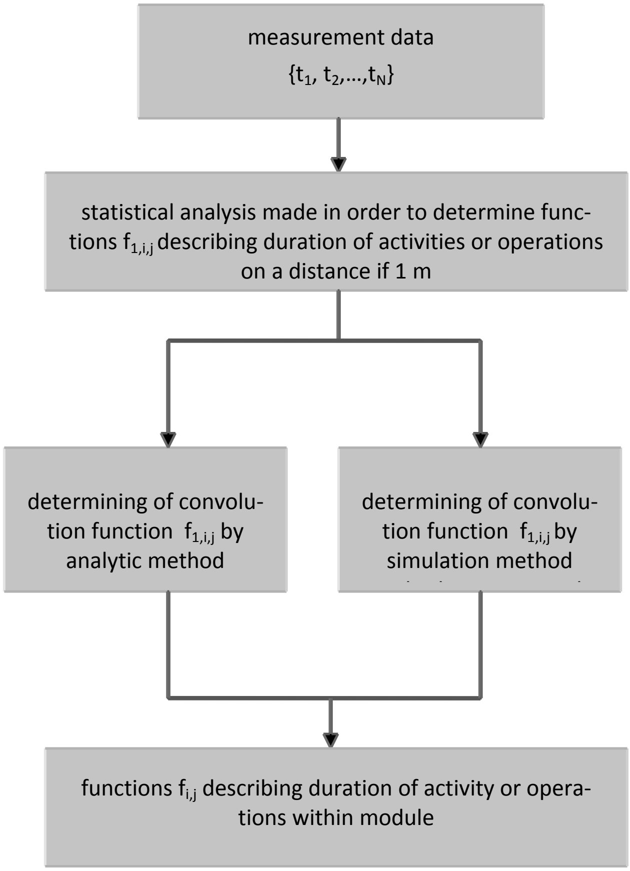

Fig. 3 Scheme of determining functions describing duration of activities or operations in the module.
Source: Authors materials

Range of activity realized in given module is marked with symbol "*S*" in the scheme. If this range is for example 15 m, $S = 15$. Assumed number of simulations is marked with symbol "*LS*".

If the module comprises activities and operations, which can be executed by various number of workers (crew) the function $f_{i,j}$ is determined for each crew selection variant separately. Marking $f_{i,j}^k$, where symbol "*k*" comprises crew, for which function $f_{i,j}$ was determined has been introduced in order to differentiate the mentioned functions. Procedure of selection the crew within the modules with use of the function $f_{i,j}^k$. is characterized in next parts of this study.

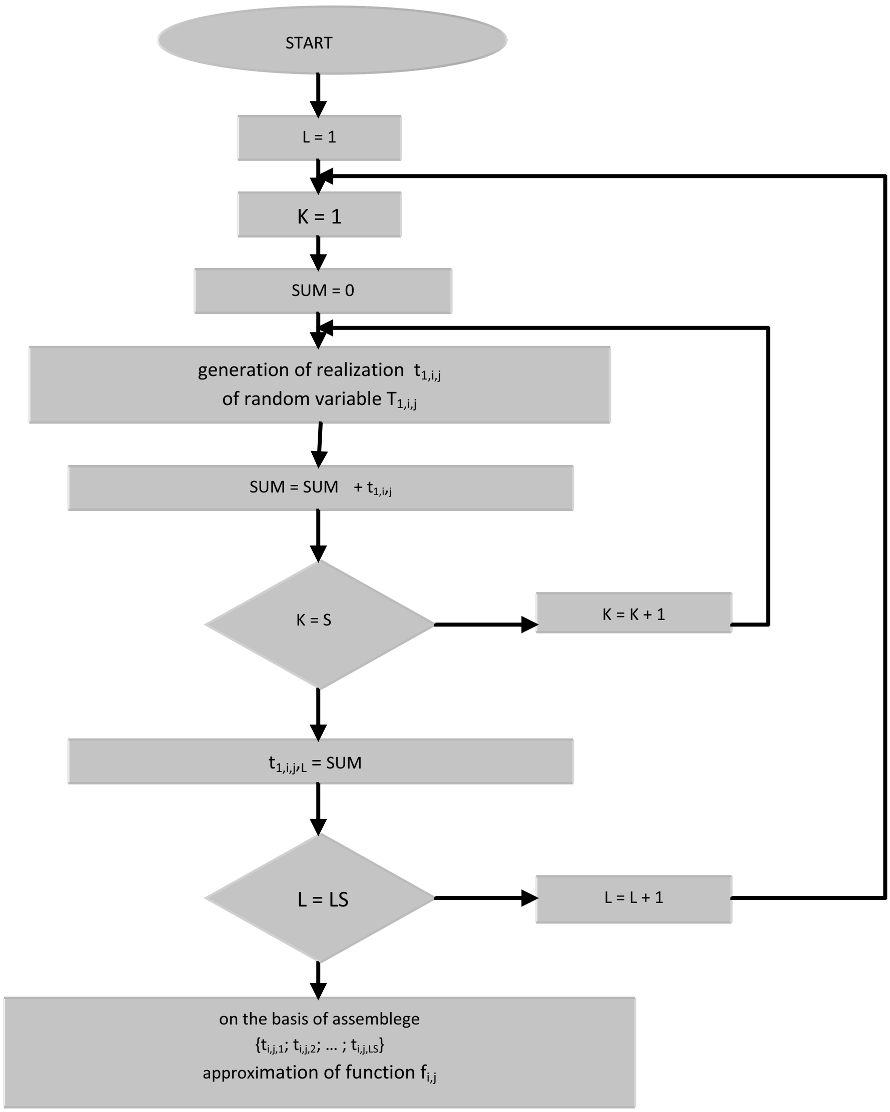

Fig. 4. Scheme of determining the function with use of simulation method.
Source: Authors materials

4. Selection of crew for individual module of the production process

Crew of the whole production process realized in the longwall face is determined for each module of the production process. In order to select four module types, algorithms of crew selection taking into account this differentiation is described in next parts of this study.

4.1. Algorithm for the crew selection for modules with parallel and leading operations

According to mentioned description, leading activity or operations is defined as activity or operation, which realization shouldn't be stopped within given module (it shouldn't "wait" for execution of other activities or operations).

Operation of the shearer in longwall face is an ex ample of such activity in production process. The shearer shouldn't wait until the mechanized support of conveyor is shifted. Each stoppage of the shearer advance is inconvenient from the production efficiency point of view. Thus in the module, in which leading activity occurs, the crew selection procedure takes under consideration the mentioned conditions.

Example of module, in which leading activity occurs is shown in Fig. 5.

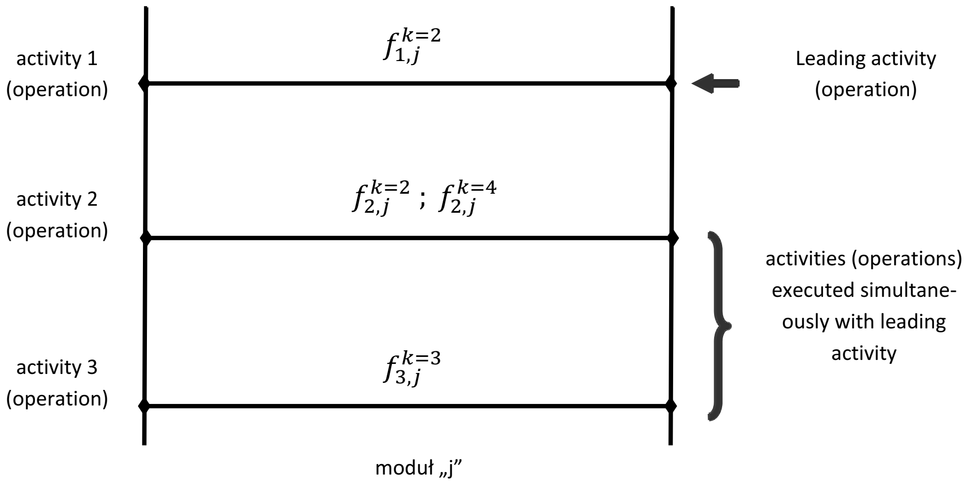

Fig. 5. Example of the module with leading activity (operations).
Source: Authors materials

Symbols used in Fig. 5:

$f_{1,j}^{k=2}$ – function density, describing duration of activity (operation) 1 in module "j" for crew $k = 2$,

$f_{2,j}^{k=2}$ – density function, describing duration of activity (operation) 2 in module "j" for crew $k = 2$,

$f_{2,j}^{k=4}$ – density function, describing duration of activity (operation) 2 in module "j" for crew $k = 4$,

$f_{3,j}^{k=3}$ – density function describing duration (operation) 3 in module "j" for crew $k = 3$.

Module "j" can be realized for two crew variants:

- Variant I – 7 persons crew, activities (operations) realized according to function $f_{1,j}^{k=2}, f_{2,j}^{k=2}, f_{3,j}^{k=3}$,
- Variant II – 9 persons crew, activities (operations) realized according to function $f_{1,j}^{k=2}, f_{2,j}^{k=4}, f_{3,j}^{k=3}$.

Scheme of the crew selection in module "j" is divided into the following stages:

Stage I

Calculation of the value t_0 for complex probability p according to formula:

$$\int_{-\infty}^{t_0} f_{1,j}^{k=2}(t)\,dt = p \tag{1}$$

where:

p — probability of realization of the leading activity in time shorter than t_0 (level 0,95 is recommended),

t_0 — determined boundary value of the leading activity (operations) in module "j", for which probability of exceeding amounts for $1 - p$ (for $p = 0{,}95$, this probability amounts for only 0,05)

Stage II

Calculation of the probability of activities (operations) realization, which are executed in time sorter than t_0 for all variants of the crew selection module "j".

Variant I

In the first variant, the crew selection is realized by 7 persons and activities (operations) are characterized by functions $f_{1,j}^{k=2}, f_{2,j}^{k=2}, f_{3,j}^{k=3}$. The following integrals marked with symbols 2 and 3 should be calculated in order to calculate the probabilities:

$$\int_{-\infty}^{t_0} f_{2,j}^{k=2}(t)\,dt = p_{2,j}^{k=2} \tag{2}$$

$$\int_{-\infty}^{t_0} f_{3,j}^{k=3}(t)\,dt = p_{3,j}^{k=3} \tag{3}$$

Variant II

In the second variant the crew is realized by 9 persons and the activities (operations) are characterized by functions $f_{1,j}^{k=2}, f_{2,j}^{k=4}, f_{3,j}^{k=3}$. The searched probabilities are calculated from fomulas:

$$\int_{-\infty}^{t_0} f_{2,j}^{k=4}(t)\,dt = p_{2,j}^{k=4} \tag{4}$$

whereas $p_{3,j}^{k=3}$ from formula 3.

Stage III

Procedure of the variant of the crew selection on the basis of values of calculated probabilities. Three options are distinguished in this procedure:

Option 1. All calculated probabilities are greater than p, thus $p_{2,j}^{k=2} > p$; $p_{3,j}^{k=3} > p$; $p_{2,j}^{k=4} > p$ (for module "*j*"). In practice it means that in no crew selection variant occur, which can stop leading activities (operations). In this case, variant of the crew selection with the minimal number of workers should be selected. In the cited example it is variant I, for which the crew consists of 7 persons.

Option 2. Only in one variant the calculated probabilities are greater than p. That means that the only one variant of the crew selection assures execution of activities (operations) in the module in such manner that the realization of the leading activity is not stopped. In this case, crew selection assumed in this variant is taken as the module crew.

Option 3. All calculated probabilities are smaller than p. For the ex ample value it means that: $p_{2,j}^{k=2} < p$; $p_{3,j}^{k=3} < p$; $p_{2,j}^{k=4} < p$

In practice it means that none crew variant assures execution of the activity (operation) in sorter time than the leading activity, i.e. the leading activity will be stopped. In such situation possibility of crew size should be considered. If there is no such possibility, variant for which calculated probabilities are closest to value p are considered. Based on the dada from example the following quotients should be calculated:

– for variant I: $\dfrac{p_{2,j}^{k=2} + p_{3,j}^{k=3}}{2}$,

– for variant II: $\dfrac{p_{2,j}^{k=4} + p_{3,j}^{k=3}}{2}$.

Variant, for which the quotient is larger, should be considered as the variant of the crew selection of module "*j*".

Analogical calculations can be executed for selection of optimal variant of the crew selection if only a part of calculated probabilities satisfies assumed criterion (are smaller than p). In practice it means that activities (operations), which can stop execution of the leading activity can occur in each variant of the crew selection procedure. However, following the mentioned calculation procedure we are able to select such crew, which assures minimized stoppages of activity (operation), which is considered as leading activity.

4.2. Algorithm of crew selection for a module with parallel activities or operations without leading operations

Example of the model with two parallel operations, where none of them is leading.

The following symbols were used in Fig:

$f_{1,j}^{k=1}$ – density function, describing time of the activity (operation) 1 realization in module "*j*" for the crew $k = 1$,

$f_{1,j}^{k=2}$ – density function, describing time of the activity (operation) 1 realization in module "*j*" for the crew $k = 2$,

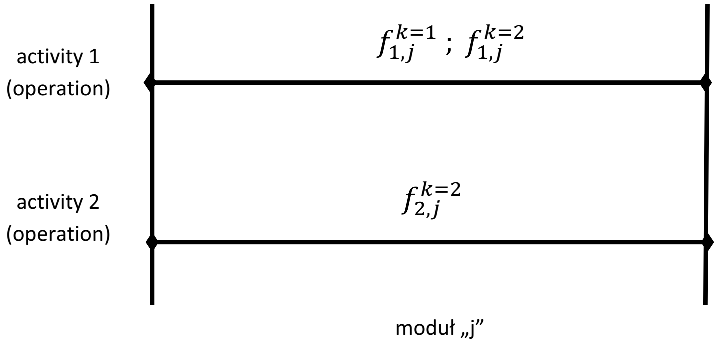

Fig. 6. Example of the module with activities (operations) executed simultaneously without leading activity
Source: Authors materials

$f_{2,j}^{k=2}$ – density function, describing time of the activity (operation) 2 realization in module "*j*" for the crew $k = 2$.

Module "*j*" can be realized in two options:

– Variant I – 3 person crew, activities (operations) realized according to function $f_{1,j}^{k=1}, f_{2,j}^{k=2}$,
– Variant II – 4 person crew, activities (operations) realized according to function $f_{1,j}^{k=2}, f_{2,j}^{k=2}$.

Procedure of the crew selection in module with paralel activities (operations) without leading operations comprises the following stages:

Stage I

Value of the boundary module realization time, which probability indicates that the limit will not bee exceeded is *p*, is calculated for each crew variant. Thus further calculations executed with respect to assumed probability level *p*. value of $p = 0.95$ are recommended, (like confidence level), although specific value depends on person performing the calculations. The calculations are as follow:

Variant I

$$\int_{-\infty}^{t_{1,j}^{k=1}} f_{1,j}^{k=1}(t)dt = p \tag{5}$$

$$\int_{-\infty}^{t_{2,j}^{k=2}} f_{2,j}^{k=2}(t)dt = p \tag{6}$$

$$t_0^{W_I} = \max\left\{t_{1,j}^{k=1}; t_{2,j}^{k=2}\right\} \tag{7}$$

where:

$t_0^{W_I}$ — boundary module realization time for variant I, not exceeding probability amounting for p.

Variant II

$$\int_{-\infty}^{t_{1,j}^{k=2}} f_{1,j}^{k=2}(t)dt = p \tag{8}$$

$t_{2,j}^{k=2}$ — calculated from formula 6,

$$t_0^{W_{II}} = \max\left\{t_{1,j}^{k=2}; t_{2,j}^{k=2}\right\} \tag{9}$$

where:

$t_0^{W_{II}}$ — boundary module realization time for variant II, not exceeding probability amounting for p.

Stage II

Calculation of this variant of the crew selection W_i, assures the shortest realization time of this module, thus:

$$t_0^{W_i} = \min\left\{t_0^{W_I}; t_0^{W_{II}}\right\} \tag{10}$$

For ex ample, if the time is the shortest $t_0^{W_{II}}$ (for variant II), the crew, which should realize activities (operations) in module "*j*" comprises 4 persons, whereas the activity (operation) „2" should be realized also by two persons. The calculations were executed for assumed probability level p.

4.3. Algorithm of the crew selection for module with activities (operations) executed in series

Example of module with two activities executed in series is shown in Fig. 7.

The following symbols were used in Fig. 7:

$f_{1,j}^{k=1}$ – density function, describing time of activity (operation) 1 realization in module "*j*" for crew $k = 1$,

$f_{1,j}^{k=2}$ – density function, describing time of activity (operations) realization 1 in module "*j*" for crew $k = 2$,

$f_{2,j}^{k=3}$ – density function, describing time of activity (operations) realization 2 in module "*j*" for crew k = 3.

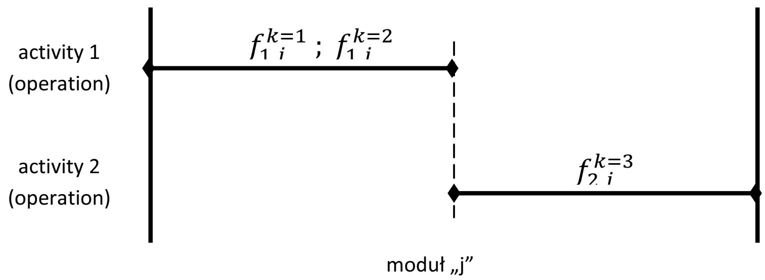

Fig. 7 Example of the module with activities (operations) executed in series
Source: Authors materials

Module "*j*" can be realized in two variants:

– Variant I – 4 person crew, activities (operations) realized according to function $f_{1,j}^{k=1}, f_{2,j}^{k=3}$,

– Variant II – 5 person crew, activities (operations) realized according to function $f_{1,j}^{k=2}, f_{2,j}^{k=3}$.

Scheme of the module crew selection with activities (operations) executed in series comprises the following stages

Stage I

Function describing realization time of module "*j*" is determined for each crew variant. These functions are determined with use of convolution operations and it has the following form:

Variant I

$$f_j^{W_I} = f_{1,j}^{k=1} \otimes f_{2,j}^{k=3} \tag{11}$$

where:

$f_j^{W_I}$ — density function of random variable time of realization of module "*j*" for variant I.

Variant II

$$f_j^{W_{II}} = f_{1,j}^{k=2} \otimes f_{2,j}^{k=3} \tag{12}$$

where:

$f_j^{W_{II}}$ — density function of random variable time of realization of module "*j*" for variant II.

Stage II

Boundary value of time of realization of module "*j*", not exceeding probability amounting for *p* is determined for each crew selection variant. The calculations are as follow:

Variant I

$$\int_{-\infty}^{t_0^{W_I}} f_j^{W_I}(t)dt = p \tag{13}$$

where:

$t_0^{W_I}$ — boundary realization time for variant I, not exceeding probability p.

Variant II

$$\int_{-\infty}^{t_0^{W_{II}}} f_j^{W_{II}}(t)dt = p \tag{14}$$

where:

$t_0^{W_{II}}$ — boundary realization time for variant II, not exceeding probability p.

Stage III

Determination of the crew selection variant W_i, which assures the shortest realization time of given module:

$$t_0^{W_i} = \min\left\{t_0^{W_I}; t_0^{W_{II}}\right\} \tag{15}$$

For example, if the time $t_0^{W_{II}}$ is the shortest (for variant II), the crew which should realize the activities (operations) in module "j" amounts for 5 persons, whereas realization time of this module can not exceed value $t_0^{W_{II}}$ with probability p, if the first activity (operation) will be executed by two persons and the second activity (operation) is executed by three persons.

4.4. Algorithm of the crew selection for module with activities or operations executed both in parallel and in series

Example of module with activities executed in series is shown in Fig. 8. The second activity can be executed in two crew variants.

Symbols used in Fig. are as follow:

$f_{1,j}^{k=2}$ – Density function describing time of realization of activity (operation) 1 in module "j" for crew $k = 2$,

$f_{2,j}^{k=2}$ – Density function describing time of realization of activity (operation) 2 in module "j" for crew $k = 2$,

$f_{2,j}^{k=2}$ – Density function describing time of realization of activity (operation) 3 in module "j" for crew $k = 2$,

$f_{4,j}^{k=2}$ – Density function describing time of realization of activity (operation) 4 in module "j" for crew $k = 2$.

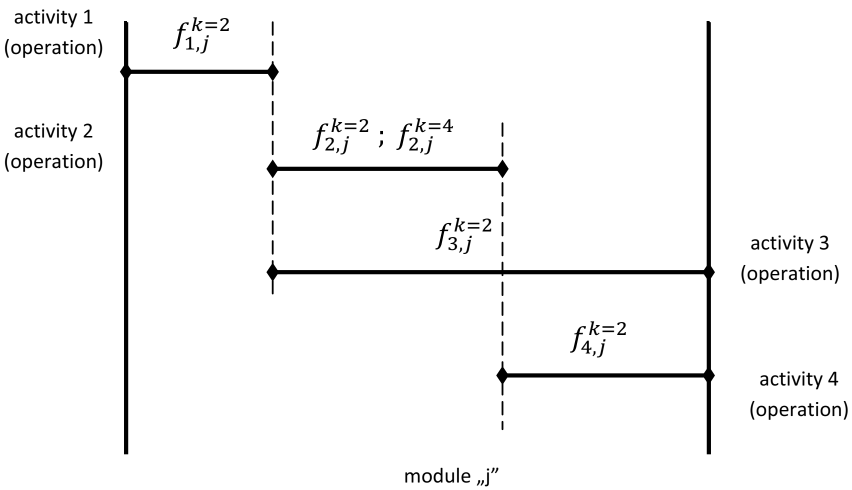

Fig. 8. Example of the module with activities (operations) executed in series and in parallel.
Source: Authors materials

Module "*j*" can be realized in two crew variants:

– Variant I – 8 persons crew, activities (operations) realized according to function $f_{1,j}^{k=2}, f_{2,j}^{k=2}, f_{3,j}^{k=2}, f_{4,j}^{k=2}$,
– Variant II – 10 persons crew, activities (operations) realized according to function $f_{1,j}^{k=2}, f_{2,j}^{k=4}, f_{3,j}^{k=2}, f_{4,j}^{k=2}$.

Scheme of crew selection in the module with activities (operations) executed both in series and in parallel, comprises the following stages:

Stage I

Calculation of the module duration with use of complex probability level p, for each crew variant. Concept of full paths was introduced into calculations. Full paths are defined as a set of successive activities (operations), from which the first activity is started in the initial point of the module and the last one is finished in final point of the module. Two full paths marked with symbols S_1 and S_2 can by distinguished for the module presented in Fig. 8. Path S_1 comprises activities (operations) 1,2 and 4, whereas path S_2 comprises activities (operations) 1 and 3.

Functions describing duration of full paths are developed for all crew variants, as convolution of suitable functions in the following manner:

Variant I

$$f_j^{S_1,W_I} = f_{1,j}^{k=2} \otimes f_{2,j}^{k=2} \otimes f_{4,j}^{k=2} \tag{16}$$

$$f_j^{S_2,W_I} = f_{1,j}^{k=2} \otimes f_{3,j}^{k=2} \tag{17}$$

where:

$f_j^{S_1,W_I}$ — density function describing duration of path S_1 for crew variant W_I in module "j",

$f_j^{S_2,W_I}$ — density function describing duration of path S_2 for crew variant W_I in module "j".

Variant II

$$f_j^{S_1,W_{II}} = f_{1,j}^{k=2} \otimes f_{2,j}^{k=4} \otimes f_{4,j}^{k=2} \tag{18}$$

$$f_j^{S_2,W_{II}} = f_{1,j}^{k=2} \otimes f_{3,j}^{k=2} \tag{19}$$

where:

$f_j^{S_1,W_{II}}$ — density function describing duration of path S_1 for crew variant W_{II} in module "j",

$f_j^{S_2,W_{II}}$ — density function describing duration of path S_2 for crew variant W_{II} in module "j".

Stage II

Duration of module "j" with not exceeding probability p is determined for each crew variant. Calculations for each variants are as follow:

Variant I

The following integrals should be calculated in order to determine time $t_0^{S_1,W_I}$ and $t_0^{S_2,W_I}$:

$$\int_{-\infty}^{t_0^{S_1,W_I}} f_j^{S_1,W_I}(t)dt = p \tag{20}$$

$$\int_{-\infty}^{t_0^{S_2,W_I}} f_j^{S_2,W_I}(t)dt = p \tag{21}$$

where:

$t_0^{S_1,W_I}$ — duration of path S_1 in crew variant W_I, not exceeding probability p,

$t_0^{S_2,W_I}$ — duration of path S_2 in crew variant W_I, not exceeding probability p.

Duration of module "j" for crew variant W_I, not exceeding probability p, is calculated from formula:

$$t_0^{W_I} = \max\left\{t_0^{S_1,W_I}; t_0^{S_2,W_I}\right\} \tag{22}$$

where:

$t_0^{W_I}$ — duration of module "j" for crew variant W_I, not exceeding probability p.

Variant II

In order to determine time $t_0^{S_1,W_{II}}$ and $t_0^{S_2,W_{II}}$ we should calculate:

$$\int_{-\infty}^{t_0^{S_2,W_{II}}} f_j^{S_1,W_{II}}(t)dt = p \tag{23}$$

$$\int_{-\infty}^{t_0^{S_2,W_{II}}} f_j^{S_2,W_{II}}(t)dt = p \tag{24}$$

where:

$t_0^{S_1,W_{II}}$ — duration of path S_1 in crew variant W_{II}, not exceeding probability p,

$t_0^{S_2,W_{II}}$ — duration of path S_2 in crew variant W_{II}, not exceeding probability p.

Duration of module "*j*" for crew variant W_{II}, not exceeding probability p, is calculated from formula:

$$t_0^{W_{II}} = \max\left\{t_0^{S_1,W_{II}}; t_0^{S_2,W_{II}}\right\} \tag{25}$$

where:

$t_0^{W_{II}}$ — duration of module "*j*" for crew variant W_{II}, not exceeding probability p.

Stage III

For handling the activity (operation) of module "*j*" should be assumed such crew variant W_i, which assures the shortest time of the module realization, thus:

$$t_0^{W_i} = \min\left\{t_0^{W_I}; t_0^{W_{II}}\right\} \tag{26}$$

where:

$t_0^{W_i}$ — the shortest time of realization of module "*j*" for crew variant W_i.

For example, if time $t_0^{W_{II}}$ (for variant II) is the shortest, the crew, which should realize activities (operations) in module "*j*" amounts for 10 persons, whereas the first activity (operation) should be executed by two persons, the second activity (operation) – four persons, the third activity (operation) by two persons and the forth activity (operation) also by two persons. The calculations were executed with assumed probability p.

5. Final conclusions

Observations of durations of activities (operations) executed in production process confirm the thesis that these times are exposed to some fluctuations resulting from mining and geological conditions. The method proposed in this study assumes application of probability density function of durations of the executed activities for the longwall face selection. Different from the deterministic approach, i.e. considering the activity realization times as random variables was applied in the proposed method.

Application of the developed method requires execution of some activities, from which the most important are:

- identification of key activities of the production process,
- division of the production process into characteristic modules, with respect to simultaneity of the activities realization,
- identification of the density functions of the durations of executed activities within separated module,
- assuming preliminary crew variants for individual module,
- optimization the crew selection in module via taking under consideration probabilities of the activities realization for assumed crew, according to the module character.

It should be also noted that:

1. Each production process can be divided into finite number of modules differing with simultaneity of the activity realization.
2. Isolation of the modules from production process allows easier analysis of the production process and in consequence proper crew selection.
3. The applied criterion of the probability of achieving assumed module realization duration allows rational crew selection because module realization as a whole has higher priority than realization of individual activities.

References

Snopkowski R., 1990. *Numerisches Modell des Produktionsprozesses verwirklicht in einem Strebstoss des Kohlenbergwerks*. Arch. Min. Sci., Vol. 35, No 4, p. 617-630.

Snopkowski R., 1994. *Die Kritikalitätsrichtwerte in der Bewertung der Einflusswahrscheinlichkeit der Tätigkeiten und des am Strebstoss Ausgeführten Arbeitsganges auf die Gewinnung*. Arch. Min. Sci., Vol. 39, No 1, 1994 p. 111-126.

Snopkowski R., 2000. *Metoda identyfikacji rozkładu prawdopodobieństwa wydobycia uzyskiwanego z przodków ścianowych kopalń węgla kamiennego*. Uczelniane Wydawnictwa Naukowo-Dydaktyczne, seria Rozprawy Monografie, nr 85.

Snopkowski R., 2000. *Boundary conditions for elementary functions of probability densities for the production process realized in longwalls*. Arch. Min. Sci., Vol. 45, No. 4, p. 501-510/

Snopkowski R., 2002. *Longwall output plan considered in probability aspect*. Arch. Min. Sci., Vol. 47, No. 3, p. 413-420.

Snopkowski R., 2005. *The use of the Stochastic Simulation for Identyfication of the Function of Output Probability Density*. Arch. Min. Sci., Vol. 50, No. 4, p. 497-504.

Snopkowski R., 2007. *The use of stochastic simulations in modeling and analysis of mining processes*. Proceedings of the 16th international conference on Systems science. Vol. 3, Applications of systems analysis to technical systems; Applications of systems analysis to non-technical systems; Applications of systems analysis to biomedical systems: Wrocław.

Snopkowski R., 2007. *Symulacja stochastyczna*. Uczelniane Wydawnictwa Naukowo-Dydaktyczne, Kraków.

Snopkowski R., 2009. *Stochastic model of the longwall face excavation using two-way shearer mining technology*. Arch. Min. Sci., Vol. 54, No. 3, 2009, p. 573-585.

Snopkowski R., Napieraj A., 2012. *Method of the production cycle duration time modeling within hard coal longwall faces*. Arch. Min. Sci., Vol. 57, Issue 1, p. 121-138.

Sukiennik M., 2011. *Metoda wyznaczania obsady w przodkach ścianowych kopalń węgla kamiennego z uwzględnieniem stochastycznego charakteru procesu produkcyjnego*, Praca doktorska, Akademia Górniczo-Hutnicza im. Stanisława Staszica, Kraków.

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