Arch. Min. Sci., Vol. 58 (2013), No 4, p. 1007–1022
Electronic version (in color) of this paper is available: http://mining.archives.pl

DOI 10.2478/amsc-2013-0070

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APPLICATION OF CLASSIFICATION AND SYSTEMATIZATION METHODS IN ASSESSMENT OF THE LEVEL OF ASSOCIATED HAZARDS IN THE EXPLOITATION AREAS

ZASTOSOWANIE METOD KLASYFIKACJI I SYSTEMATYZACJI ZBIORÓW DO OCENY POZIOMU ZAGROŻEŃ SKOJARZONYCH W REJONACH EKSPLOATACYJNYCH

In Polish coal mines as the extraction descents to the increasing depth, the risk of methane and spontaneous fire is observed. The coexistence of these two hazards enforces at the design phase and during extraction, the assessment in terms of the selection of a prevention scope for their eradication. Based on a set of indicators and parameters describing the level of co-occurrence of both threats on a set of 75 longwalls extracted in Polish hard coal mines, their classification and systematization was performed with the use of statistical methods.

Adoption of the methods described in the publication made it possible to split the set of 75 longwalls into statistically homogeneous subsets, characterizing similar longwalls, and the development of a synthetic evaluation instrument, with the coexistence of hazards allowed to_calculate for each longwall its dimensionless value that is a reflection of the level of associated risk. The calculation results reflect with high probability the actual level of associated hazards when mining these longwalls.

Keywords: mining activities, methane, endogenous fire risk, explosion risks

W polskich kopalniach wegla kamiennego wraz ze schodzeniem z eksploatacją na coraz większą głębokość obserwuje się wzrost zagrożenia metanowego oraz pożarami endogenicznymi. Współwystępowanie obu tych zagrożeń wymusza na etapie projektowania oraz eksploatacji dokonywanie oceny pod kątem doboru zakresu profilaktyki dla ich zwalczania. W oparciu o zestaw wskaźników i parametrów opisujących poziom współwystępowania obu zagrożeń na zbiorze 75 ścian eksploatowanych w polskich kopalniach węgla kamiennego, metodami statystycznymi przeprowadzono ich klasyfikację i systematyzację.

Zastosowanie metod przedstawionych w publikacji pozwoliło na podział zbioru 75 ścian na podzbiory statystycznie jednorodne, charakteryzujące ściany podobne, a opracowanie syntetycznego miernika oceny, przy współwystępowaniu zagrożeń, pozwoliło obliczyć dla każdej ściany bezwymiarową jego wartość będącą odzwierciedleniem poziomu występującego zagrożenia skojarzonego. Wyniki obliczeń z dużym prawdopodobieństwem odzwierciedlają faktyczny poziom występującego zagrożenia skojarzonego podczas eksploatacji tych ścian.

Słowa kluczowe: eksploatacja węgla, metan, zagrożenie pożarami endogenicznymi, zagrożenia wybuchem

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1. Introduction

Mining at the increasing depth in hard coal mines in Poland in conditions of the increasing concentration of extraction, contributes to the growth of all natural hazards. With the coexistence of natural hazards, the largest increase of associated methane and spontaneous fire hazard is observed, especially in the environment of longwalls.

Designing the exploitation of methane deposits as well as deposits with spontaneous fire risk, should take into account the significance of the occurrence of these risks in terms of the selection of appropriate prevention in their control.

Used in Polish hard coal mines, the criteria for methane hazard assessment for projected and mined longwalls included in "The Rules for Driving Longwalls ..." (*Zasady prowadzenia..., 2004*), allow the identification of the occurring methane hazard in terms of the selection of the parameters and the way of ventilating walls as well as the appropriate scope of prevention to combat this hazard. Projecting longwalls in methane deposits with simultaneously occurring coexistence of spontaneous fire risk, necessitates pre-emptive analyses of parameters and factors for the assessment of the level of occurrence of these hazards.

It should be noted that most of the parameters and indicators used in prevention means against methane and spontaneous fire hazards in longwalls act as a stimulant from one threat while being detrimental to the other threat (Krause, 2009).

In this paper, a statistical method was used to enable the level of associated risk in mined longwalls in Polish hard coal mines in 2011 to be identified. The statistical method of hazard assessment: methane and spontaneous fire allows the identification and similarity of associated risks in extracted longwalls in light of the accepted parameters and variables describing and shaping both threats. The adopted method allows us to divide a set of lonwalls, covered by the analysis, into the statistically homogeneous subsets within the scope, which the inference will be more justified, rather than with respect to the whole set. The developed synthetic dimensionless instrument of the associated risk assessment; of methane and spontaneous fire for each longwall allows for the level of risk between the created subsets and every longwall to be compared. The assessment of associated risk, conducted on a set of 75 longwalls driven in underground coal mines in 2011, enabled to select longwall subsets characterized by the similarity of the occurring associated risk. Moreover, based on the calculated value for each evaluation instrument of longwall, it allowed for an assessment of the level of methane, spontaneous fire and combined hazard.

2. Statistical Analysis of the Relationship Between the Parameters and Indicators that Describe the Associated Risk

Based on the opinions of experts, a set of parameters and factors were selected that have an impact on the formation of methane and fire hazards in mined longwalls. Out of an extensive set of parameters and indicators describing the longwalls under inquiry, those that were selected, which in the opinion of practitioners the should be included in the initial set for statistical analysis. The inquiry encompassed longwalls extracted in 2011 in the mines of Kompania Węglowa S.A., Katowicki Holding Węglowy S.A. and Jastrzębska Spółka Węglowa S.A..

Out of all longwalls surveyed, the statistical analysis was limited to the set of 75 longwalls, except for longwalls located in the seams:

- where methane does not occur (seams considered non-methane) and not within the methane field,
- in which methane does not occur, within the limits of methane fields of relevant categories,
- of methane content not exceeding 2.5 m^3CH_4/Mg_{csw}, i.e. class I of methane hazard,
- into which methane is not emitted or it is emitted in the amounts lower than 0.5 m^3 CH_4/min.

The inclusion in the calculation of longwalls, into which methane is not emitted would distort the intended research aim of the associated risk assessment associated.

The initial set included 16 parameters and indicators shaping and describing methane and fire hazards in extracted longwalls, namely:

X_1 – primary temperature of rock mass, °C
X_2 – average methane content at the edges of exploitation field of longwall, m^3CH_4/Mg_{csw},
X_3 – occurrence of coal layers in the roof of direct caving of thickness >0.2m,
X_4 – occurrence of seams in longwall's floor with a thickness of > 0.2 m,
X_5 – longwall length, m/d
X_6 – longwall height, m
X_7 – longwall advance, m/d
X_8 – output, Mg/d
X_9 – indicator of ventilation system and ventilation methane content of the longwall area,
X_{10} – air consumption in the longwall area, m^3/min
X_{11} – absolute methane content, m^3/min
X_{12} – share of methane from the extracted seam in absolute methane content, %
X_{13} – share of methane from undermined and over mined seams in absolute methane content, %
X_{14} – methane drainage efficiency, %
X_{15} – exploitation system,
X_{16} – absolute relative methane content, m^3 CH_4 calculated into Mg of extracted coal.

Carrying out statistical calculations between parameters and indicators from the initial set was made on the matrix X [1:75; 1:16], creating the matrix of correlation indicators (Table 1).

The test of significance of correlation coefficients are calculated based on the size of the sample. The critical value of the correlation coefficient was obtained by the formula (1):

$$|R| > \frac{t_{kr}}{\sqrt{N-2+t_{kr}^2}} = R_{kr} \tag{1}$$

For N = 75 from the table of distribution, t - Student for $\alpha = 0.05$, $t_{kr} = 1.99$ was obtained. Inserting into the formula (1) a value was obtained of $R_{kr} = 0.23$.

In Fig. 1, a graph of correlation between the variables for which the value of correlation coefficient was higher than 0.23 is presented. The value of correlation coefficients between the variables in a graph of Fig. 1 was marked with the following colours:

- for correlation $R > 0,7$ red,
- for correlation $0,5 < R < 0,7$ blue,

TABLE 1

Correlation matrix

	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}	X_{13}	X_{14}	X_{15}	X_{16}
X_1	1.00	0.27	-0.11	0.07	-0.22	-0.05	-0.17	-0.25	0.15	0.29	0.25	-0.03	0.03	0.26	0.10	0.32
X_2	0.27	1.00	0.03	0.19	0.17	-0.25	-0.18	-0.14	0.63	0.54	0.71	-0.19	0.19	0.62	-0.36	0.72
X_3	-0.11	0.03	1.00	-0.08	0.26	-0.14	0.05	0.17	-0.04	0.06	0.08	-0.08	0.08	0.08	-0.10	0.13
X_4	0.07	0.19	-0.08	1.00	0.08	0.07	-0.03	0.11	0.20	0.08	0.08	-0.19	0.19	0.12	-0.12	0.06
X_5	-0.22	0.17	0.26	0.08	1.00	-0.16	-0.14	0.30	0.20	0.26	0.21	-0.20	0.20	0.20	-0.24	0.16
X_6	-0.05	-0.25	-0.14	0.07	-0.16	1.00	0.01	0.46	0.04	-0.11	-0.12	-0.09	0.09	-0.24	0.11	-0.28
X_7	-0.17	-0.18	0.05	-0.03	-0.14	0.01	1.00	0.64	-0.18	-0.04	-0.24	0.04	-0.04	-0.29	0.15	-0.36
X_8	-0.25	-0.14	0.17	0.11	0.30	0.46	0.64	1.00	0.06	0.12	-0.10	-0.18	0.18	-0.26	0.01	-0.33
X_9	0.15	0.63	-0.04	0.20	0.20	0.04	-0.18	0.06	1.00	0.41	0.79	-0.21	0.21	0.43	-0.20	0.64
X_{10}	0.29	0.54	0.06	0.08	0.26	-0.11	-0.04	0.12	0.41	1.00	0.57	-0.28	0.28	0.41	-0.37	0.52
X_{11}	0.25	0.71	0.08	0.08	0.21	-0.12	-0.24	-0.10	0.79	0.57	1.00	-0.33	0.33	0.68	-0.28	0.92
X_{12}	-0.03	-0.19	-0.08	-0.19	-0.20	-0.09	0.04	-0.18	-0.21	-0.28	-0.33	1.00	-1.00	-0.42	0.32	-0.26
X_{13}	0.03	0.19	0.08	0.19	0.20	0.09	-0.04	0.18	0.21	0.28	0.33	-1.00	1.00	0.42	-0.32	0.26
X_{14}	0.26	0.62	0.08	0.12	0.20	-0.24	-0.29	-0.26	0.43	0.41	0.68	-0.42	0.42	1.00	-0.29	0.71
X_{15}	0.10	-0.36	-0.10	-0.12	-0.24	0.11	0.15	0.01	-0.20	-0.37	-0.28	0.32	-0.32	-0.29	1.00	-0.27
X_{16}	0.32	0.72	0.13	0.06	0.16	-0.28	-0.36	-0.33	0.64	0.52	0.92	-0.26	0.26	0.71	-0.27	1.00

– for correlation $0{,}4 < R < 0{,}5$ grey,
– for correlation $0{,}3 < R < 0{,}4$ green,
– for correlation $R_{kr} < R < 0{,}3$ yellow.

After the analysis of the correlation matrix from Table 1 and Fig. 1, it shows that the adopted variables of the initial set characterize with a various degree of correlation. The correlation between some parameters and factors of the adopted initial set confirms the occurrence of strong statistical relations. High correlation coefficients above 0.7 is characteristic for variable X_{11} i.e. absolute methane content. The variable X_{11} is correlated with parameters: X_2 – which is the average methane content at the edge of the exploitation field of the longwall, X_9 – an indicator of a ventilation system and ventilation methane content of the longwall area and X_{16} – the relative methane content. Equally high coefficients of correlation have the variables: X_2 – the average methane content at the edges of the exploitation field of the longwall with the variable X_{16} – a relative methane content, X_{12} – a share of methane from the extracted seam in absolute methane content with the variable X_{13} – a share of methane from undermined and over mined seams in absolute methane content, X_{16} – an absolute relative methane content with methane drainage efficiency – X_{14}, due to the fact that these variables should not be considered in further analysis. The value of the variables of correlation coefficients: X_6 – the height of the longwall and X_7 – the longwall advance with a variable X_8 – output, indicates that the first ones should not be included in the further analysis. Despite the value of the correlation above the critical value 0.23, between some of the variables, owing to their considerable significance in the assessment of methane or fire hazard they have been adopted for further calculation, after verification into a set of 10 indicators and parameters describing both hazards.

The carried out analysis based on the correlation between the parameters describing methane and fire hazards, helped to identify strong correlated parameters, which should not be included in the reduced output set to perform the classification and systematization of longwalls into sta-

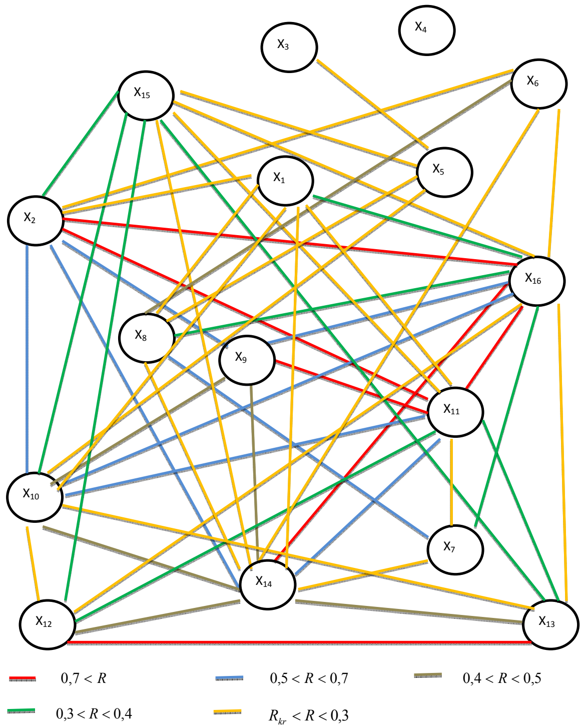

Fig. 1. A graph of the correlation between the parameters and indicators that describe the evolution of methane and fire hazards

tistically homogeneous subsets. A revised set of ten variables (Fig. 2) taken as a base for further calculations are:

- X_1 – primary temperature of rock mass, °C
- X_3 – occurrence of coal layers in the roof with a direct caving with a thickness of > 0.2 m,
- X_4 – occurrence of seams in longwall's floor with a thickness of > 0.2 m,
- X_5 – length of longwall, m
- X_8 – output, Mg/d
- X_9 – indicator of a ventilation system and ventilation methane content of the longwall area,
- X_{10} – air consumption in the region of longwall, m^3/min
- X_{13} – share of methane from undermined and over mined seams in absolute methane content, %
- X_{14} – methane drainage efficiency, %
- X_{15} – extraction system,

The carried out analysis of the correlation between the parameters and indicators of the output set that describing the formation of methane and fire hazard in longwalls, made it possible to identify the degree of their dependence on each other in the adopted output set that describes both threats.

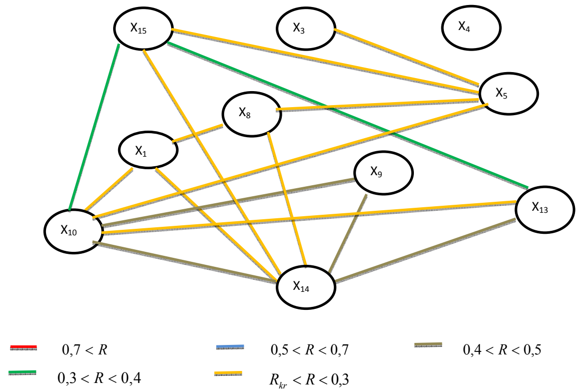

Fig. 2. A reduced graph of correlation of parameters and indicators weakly correlated

3. The Method of Classification and Systematization of Sets of Longwalls Extracted in 2011 in Polish Hard Coal Mines

Statistical analysis of methane and fire hazards for 75 longwalls were based on the division of the set into subsets statistically homogeneous, in which inferences about the level of hazard will be justified rather than for the whole set.

Statistical methods enabling to undertake a classification of sets are taxonomic methods, including the method of grouping multidimensional random variables.

Analysis and assessment of the associated risk in longwalls, in which at the same time there is a methane hazard and spontaneous fire hazard, based on the methods of classification and systematization of sets will allow to:

- select a subset of homogeneous longwalls characterized by a high level of associated risk,
- predict a subset of homogeneous longwalls characterized with low level of associated risk,
- conduct a comparative analysis of longwalls in the created statistically homogeneous subsets,
- select from the set of all longwalls under the analysis of those, which subsets make up the one-element subsets, i.e. single longwalls not characterized by the similarity to other longwalls,

The classification of longwalls by grouping multidimensional random variables, enables observation of the movement and the joining of longwalls and subsets in homogeneous subsets as well as providing the calculated results in the form of a continuous grouping of individual objects from set (Ziembicki & Bruski, 1975) and (Kozdrój & Przybyła, 1986) under analysis. This method consists in creating from a set of all longwalls, such subsets of longwalls so that within each subset there were no significant differences between the variables describing the methane and the fire hazard in longwalls.

As the first step, each longwall X_j ought to be treated as a multidimensional random variable $X_j = \{x_{j1}, x_{j2}, \dots, x_{jm}\}$ where x_{ji} are features describing a given longwall X_j.

At the initial stage of grouping, the number of subsets is equal to the number of 75 longwalls. Between given groups with the use of the formula (2), all possible distances between the groups are calculated:

$$d_{kl} = \sqrt{\sum_{i=1}^{m} (x_{ki} - x_{li})^2} \tag{2}$$

Among all lengths d_{kl}, a smallest length is searched d_{min} and numbers of groups s and t, are determined for which this dependence takes place. Groups X_s and X_t are merged into one group, calling it number 1. The total number of groups decreases and it is equal to $L = N - 1$. The whole course of action is repeated until the moment when only one group is received. During the grouping it may happen that the new group will origin as a result of merging two formerly created groups. The new group characterizes with variable average X_{GP} – formula (3), which components are average values of all variables forming this group:

$$x_{(Gp)i} = \frac{1}{N_{Gp}} \sum_{k} x_{ki} \qquad (x_k \in G_p) \tag{3}$$

where N_{GP} is the numerical force of random variables forming the group.

For each newly created group, (4) distances of the values of its variables from the centre of the group are calculated:

$$d_{(Gp)k} = \sqrt{\sum_{i=1}^{m} (x_{ki} - x_{(Gp)i})^2} \tag{4}$$

where k adopts numbers of random variables within the group in question.

In each step of grouping by means of the formula (5), intergroup variation of distances is calculated:

$$S_{mg}^2 = \frac{1}{L-1} \sum_{p=1}^{L} N_{Gp} \sum_{i=1}^{m} (x_{Gp} - x_i)^2 \tag{5}$$

and within-group variation, formula (6).

$$S_{wg}^2 = \frac{1}{N-L} \sum_{p=1}^{L} \sum_{k=1}^{N_{Gp}} \sum_{i=1}^{m} (x_{(p)ki} - x_{(Gp)i})^2 \tag{6}$$

Calculated values of within-group variation and intergroup variation allow to confirm the hypothesis on the identity of the centres of created groups (Ziembicki & Bruski, 1975). With the formula (7), calculating the value of variable F:

$$F = \frac{S_{mg}^2}{S_{wg}^2} \tag{7}$$

It can be compared with the value $F\alpha$ read from Fischer-Snedecor tables at the level of significance $\alpha = 0.05$ with degrees of freedom $r_1 = L - 1$ and $r_2 = N - L$, where L – number of created subsets and N – number of examined longwalls. The optimal division for the determined degrees of freedom is obtained after fulfilling the condition described by the formula below:

$$\frac{F}{F_\alpha} = \max \tag{8}$$

In Table 2, results of created subsets for determined degrees of freedom are juxtaposed with the calculated value of quotient F/F_α for subsequent iteractions of subsets being created. Graphical interpretation of the value of the quotient F/F_α for subsequent degrees of freedom is presented in Figure 3.

TABLE 2

Results of created subsets for subsequent degrees of freedom

Degrees of freedom		**Value F**	**Value F_α**	**Value F/F_α**	**Division of longwalls**	**Degrees of freedom**		**Value F**	**Value F_α**	**Value F/F_α**	**Division of longwalls**
r_1	r_2					r_1	r_2				
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
73	1	26.37	252.57	0.10		37	37	16.38	1.73	9.47	
72	2	26.04	19.48	1.34		36	38	15.26	1.73	8.82	
71	3	26.60	8.57	3.10		35	39	15.78	1.72	9.17	
70	4	23.19	5.68	4.08		34	40	16.40	1.72	9.54	
69	5	21.67	4.42	4.90		33	41	16.59	1.72	9.64	
68	6	20.90	3.73	5.60		32	42	16.88	1.72	9.82	
67	7	17.86	3.30	5.41		31	43	17.63	1.72	10.25	
66	8	17.18	3.00	5.73		30	44	18.04	1.72	10.49	
65	9	16.80	2.78	6.04		29	45	15.27	1.72	8.88	
64	10	16.60	2.62	6.34		28	46	13.81	1.72	8.03	
63	11	15.68	2.49	6.30		27	47	14.21	1.72	8.26	
62	12	15.62	2.38	6.56		26	48	14.81	1.73	8.56	
61	13	15.58	2.30	6.78		25	49	16.82	1.73	9.72	
60	14	15.51	2.22	6.99		24	50	18.08	1.74	10.39	
59	15	15.40	2.16	7.13		23	51	19.34	1.74	11.12	
58	16	14.97	2.11	7.10		22	52	20.54	1.75	11.74	I Optimal
57	17	14.66	2.06	7.12		21	53	12.40	1.76	7.04	
56	18	14.43	2.02	7.14		20	54	13.19	1.77	7.45	
55	19	14.91	1.99	7.49		19	55	14.21	1.78	7.98	
54	20	15.12	1.96	7.71		18	56	12.35	1.79	6.90	
53	21	14.50	1.93	7.51		17	57	12.85	1.81	7.10	
52	22	14.68	1.90	7.73		16	58	13.87	1.82	7.62	

1	2	3	4	5	6	7	8	9	10	11	12
51	23	14.64	1.88	7.79		15	59	11.71	1.84	6.36	
50	24	15.00	1.86	8.06		14	60	12.40	1.86	6.67	
49	25	14.20	1.84	7.72		13	61	13.28	1.88	7.06	
48	26	14.51	1.83	7.93		12	62	12.98	1.91	6.80	
47	27	14.33	1.81	7.92		11	63	13.46	1.94	6.94	
46	28	14.16	1.80	7.87		10	64	12.76	1.98	6.44	
45	29	14.45	1.79	8.07		9	65	13.01	2.03	6.41	
44	30	14.26	1.78	8.01		8	66	13.74	2.08	6.61	
43	31	14.55	1.77	8.22		7	67	17.32	2.15	8.06	
42	32	13.50	1.76	7.67		6	68	5.52	2.24	2.46	
41	33	13.91	1.75	7.95		5	69	5.82	2.35	2.48	
40	34	14.32	1.75	8.18		4	70	6.29	2.50	2.52	
39	35	14.75	1.74	8.48		3	71	5.18	2.73	1.90	
38	36	15.42	1.73	8.92		2	72	4.45	3.12	1.43	
						1	73	3.90	3.97	0.98	

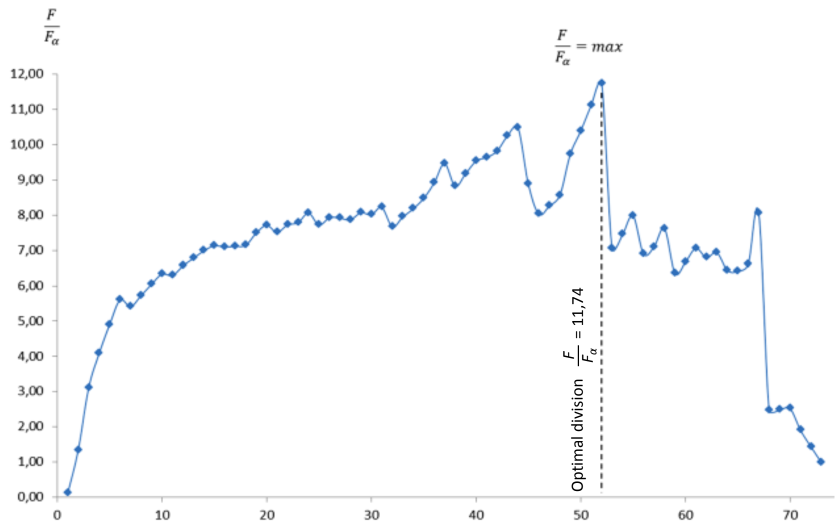

Fig. 3. Graph F/F_α of grouping longwalls with the method of random multidimensional variables with the use of Fisher's test

It results from the analysis of Table 2 and Fig. 3 that during the grouping, optimal division was selected. Table 3 presents optimal division into the number of subsets and number of longwalls forming them. The maximum value of quotient F/F_α is 11.74, thus optimal division was obtained for r_1 = 22 and r_2 = 52 degrees of freedom. In the optimal division there were 23 subsets of longwalls separated, including as many as 13 one-element subsets, and 6 – two-element. The most numerous subsets are: the first subset which included 29 longwalls and the third subset – 12 longwalls.

TABLE 3

Optimal division of longwalls set into statistically homogenous subsets

Division	Degrees of freedom	Number of subsets	Numbers of the longwalls
Optimal division	$r_1 = 22$ $r_2 = 52$	1	1, 2, 9, 11, 14, 20, 21, 24, 28, 30, 31, 33, 34, 37, 38, 40, 41, 42, 43, 44, 46, 54, 56, 59, 60, 61, 62, 63, 65
		2	7, 75
		3	3, 5, 13, 16, 23, 25, 27, 29, 32, 35, 70, 71
		4	36, 45, 51, 67, 68
		5	48, 49
		6	22, 26
		7	19, 50, 55, 57
		8	15, 53
		9	17, 47
		10	18, 69
		11-23	The remaining longwalls form one-element subsets 4, 6, 8, 10, 12, 39, 52, 58, 64, 66, 72, 73, 74

4. Measuring Tool of the Level of Associated Risk

In order to systematize longwalls in terms of the level of occurring methane and fire risk, a synthetic measure to assess both risks has been developed. A dimensionless measure of associated risk assessment calculated individually for each longwall from a set of 75 longwalls, allows the identification and comparison of the level of risk between the formed homogeneous subsets of longwalls presented in Table 3.

As the first step to determine the synthetic measure, an abstract longwall X_0 was selected with coordinates $\{X_{01}, X_{02}, \ldots, X_{0m}\}$ determined with the use of the following relations:

$$X_{0k} = \max_j X_{jk} \tag{9}$$

where k belongs to the set of stimulus features, and if k does not belong to this set, then:

$$X_{0k} = \min_j X_{jk} \tag{10}$$

where:

$j = 1, 2, ..., N$ — N – number of longwalls

$k = 1, 2, ..., m$ — m – number of parameters and indicators

Abstract longwall X_0 will be a model of the assessment.

Due to the fact that the particular parameters describing the methane hazard and fire hazard they influence one hazard in a stimulating way whilst being detrimental to the other one, to designate a synthetic measure of associated risk assessment in longwalls, two measures were calculated. The first to measure methane risk assessment and the other measure to assess the level of risk of fire. Summing the calculated values of measures, the value was determined as well as the level of associated risk in a set of 75 analysed longwalls.

In order to determine the measure of **methane hazard** assessment, the following combination of variables was adopted:

X_{14} – methane drainage efficiency, % – destimulant

X_{16} – absolute relative methane content, m^3CH_4 calculated into Mg of extracted coal – stimulant

In order to determine the measure of **fire hazard** assessment the following combination was adopted:

X_3 – occurrence of coal layers in the roof of direct caving with a thickness higher than 0.2 m – stimulant

X_7 – longwall advance, m/d – destimulant

X_{10} – air consumption in the longwall area, m^3/min – stimulant.

For calculations, to the above variations the same importance of the influence of methane and fire hazard was attributed.

In order to eliminate the impact of the selection of measure units, the values $X_{j,k}$ are standardized values, calculated by means of the formulas below:

$$\frac{X_j - \bar{x}_j}{s_j} \qquad \bar{x}_j = \frac{1}{N}\sum_{i=1}^{N} x_{ij} \qquad s_j = \left[\frac{1}{N}\sum_{i=1}^{N}(x_{ij} - \bar{x}_j)^2\right]^{\frac{1}{2}} \tag{11}$$

The fundamental elements used while calculating the synthetic measure are distances d_{jo} (formula 12) between particular points X_j and points X_0 illustrating the longwall model.

$$d_{jo} = \sqrt{\sum_{k=1}^{m}(x_{jk} - x_{ok})^2} \tag{12}$$

Synthetic measure can be calculated by means of the formula (13):

$$d_j = 1 - \frac{d_{jo}}{C} \tag{13}$$

where:

$$C = \bar{d} + 2\left[\frac{1}{N}\sum_{j=1}^{N}(d_{jo} - \bar{d})^2\right]^{\frac{1}{2}} \tag{14}$$

$$\bar{d} = \frac{1}{N}\sum_{j=1}^{N} d_{jo} \tag{15}$$

The measure d_j is constructed in such a way that it is always a negative number. It may exceed 1, yet the probability of such incident is small. It means that in the predominant number of examined longwalls the following inequality is kept:

$$0 \le d_j \le 1$$

Increasing absolute values for each measuring tool for particular longwalls indicate a potentially greater threat. The lower the value of measuring tool, the lower the threat occurring in the longwall. The measure value equal to "0" indicates the longwall constituting a 'model', characterized by the lowest level of methane or fire hazard. On the basis of carried out calculations of the measure, separately for both threats, each longwall of a set of 75, can have a position of the level of associated risk assigned by summing.

Table 4 summarizes the values of assessment measure of methane hazard (column 2) and a fire hazard (column 3) for each longwall. Column 4 presents the sum of the above columns, these are the values of the synthetic measure of the associated risk assessment. The last column of Table 4 contains positions of a synthetic measure to assess the associated risks in a set of 75 longwalls.

TABLE 4

List of measure values

No. of longwall	**Value of the measure of methane hazard assessment**	**Value of the measure of methane hazard assessment**	**Synthetic measure of associated risk assessment**	
			Value of the measure	**Measure position**
(1)	**(2)**	**(3)**	**(4)**	**(5)**
1	0.151051	0.175319	0.326370	63
2	0.375358	0.260524	0.635882	17
3	0.145486	0.265343	0.410829	55
4	0.404855	0.179394	0.584248	24
5	0.142113	0.298336	0.440449	45
6	0.139687	0.393281	0.532968	31
7	0.152153	0.265352	0.417506	51
8	0.243463	0.393274	0.636737	15
9	0.476874	0.236560	0.713434	9
10	0.210127	-0.054005	0.156122	74
11	0.225960	0.272813	0.498774	36
12	0.150631	0.285249	0.435880	46
13	0.159463	0.146026	0.305489	66
14	0.082793	0.264902	0.347695	59
15	0.149590	0.293115	0.442706	44
16	0.143604	-0.032276	0.111328	75
17	0.427008	0.152219	0.579226	25
18	0.150198	0.266934	0.417132	52
19	0.374994	0.155237	0.530231	33
20	0.296418	0.241318	0.537737	30
21	0.331269	0.337698	0.668967	12
22	0.364658	0.397302	0.761960	7
23	0.142833	0.272811	0.415644	54
24	0.282107	0.354080	0.636187	16
25	0.141332	0.281211	0.422543	50
26	0.413056	0.288355	0.701411	10
27	0.152116	0.407766	0.559883	29
28	0.177395	0.169410	0.346805	60
29	0.153083	0.279346	0.432430	47

(1)	(2)	(3)	(4)	(5)
30	0.160460	0.292432	0.452891	42
31	0.227419	0.359892	0.587311	23
32	0.171487	0.185559	0.357046	58
33	0.161989	0.115395	0.277384	70
34	0.163708	0.166059	0.329768	62
35	0.197573	0.034529	0.232102	73
36	0.163106	0.155289	0.318395	64
37	0.070326	0.207736	0.278061	69
38	0.304198	0.175319	0.479517	39
39	0.146348	0.270102	0.416450	53
40	0.237347	0.147564	0.384912	57
41	0.151085	0.249292	0.400377	56
42	0.143826	0.163733	0.307559	65
43	0.274239	0.288434	0.562673	27
44	0.161274	0.270711	0.431985	48
45	0.199623	0.072317	0.271940	71
46	0.564006	0.348246	0.912251	4
47	0.384365	0.413910	0.798275	5
48	0.143139	0.785409	0.928548	3
49	0.203109	0.781688	0.984797	1
50	0.563223	0.413900	0.977123	2
51	0.153157	0.132414	0.285570	68
52	0.486042	0.125891	0.611932	20
53	0.151528	0.309399	0.460927	41
54	0.100865	0.396548	0.497413	37
55	0.062108	0.198029	0.260137	72
56	0.219164	0.430479	0.649644	13
57	0.246120	0.322334	0.568454	26
58	0.220829	0.425578	0.646407	14
59	0.241861	0.290205	0.532066	32
60	0.264195	0.327256	0.591451	22
61	0.403266	0.206741	0.610006	21
62	0.393227	0.351861	0.745088	8
63	0.304542	0.389776	0.694319	11
64	0.181034	0.306944	0.487978	38
65	0.335715	0.278472	0.614187	19
66	0.183784	0.103807	0.287590	67
67	0.164391	0.340233	0.504624	35
68	0.172876	0.353648	0.526524	34
69	0.146507	0.184831	0.331338	61
70	0.167759	0.394047	0.561807	28
71	0.157801	0.458225	0.616025	18
72	0.516771	0.270912	0.787683	6
73	0.335221	0.115426	0.450647	43
74	0.196448	0.274318	0.470766	40
75	0.156618	0.267451	0.424069	49

The calculated values of synthetic measure enable the determination of the position of longwall in the whole set. It also allows the comparison of longwalls and state how longwalls in a given subset differ from each other. Table 5 shows the distribution of the optimal set of 75 longwalls in homogeneous subsets; moreover, a position of the values of calculated synthetic measure of associated risk assessment for each longwall was inserted.

The colour red indicates the first 20 longwalls from the set of 75 longwalls, characterized by a level of associated risk.

TABLE 5

List of results of optimal division and the position of synthetic measure of associated hazard assessment

1	**No. of longwall**	1	2	9	11	14	20	21	24	28	30	31	33	34	37	38
	Measure position	63	17	9	36	59	30	12	16	60	42	23	70	62	69	39
	No. of longwall	40	41	42	43	44	46	54	56	59	60	61	62	63	65	
	Measure position	57	56	65	27	48	4	37	13	32	22	21	8	11	19	
2	**No. of longwall**	7	75													
	Measure position	49	51													
3	**No. of longwall**	3	5	13	16	23	25	27	29	32	35	70	71			
	Measure position	55	45	66	75	54	50	29	47	58	73	28	18			
4	**No. of longwall**	36	45	51	67	68										
	Measure position	64	71	68	35	34										
5	**No. of longwall**	48	49													
	Measure position	1	3													
6	**No. of longwall**	22	26													
	Measure position	7	10													
7	**No. of longwall**	19	50	55	57											
	Measure position	33	2	72	26											
8	**No. of longwall**	15	53													
	Measure position	44	41													

9	**No. of longwall**	17	47													
	Measure position	25	5													
10	**No. of longwall**	18	69													
	Measure position	52	61													
11-23	**No. of longwall**	4	6	8	10	12	39	52	58	64	66	72	73	74		
	Measure position	24	31	15	74	46	53	20	14	38	67	6	43	40		

5. The Conclusions of the Comprehensive Statistical Methods to Assess the Associated Risks

This article presents a statistical method, developed for the assessment of associated risk in 75 longwalls operated in Polish coal mines in 2011, which made it possible to:

- divide the adopted set of 75 longwalls covered by the analysis into statistically homogeneous subsets, within which drawing inferences is more justified than for the whole set of longwalls,
- calculate the level meter for hazards: methane and fire in longwalls and calculation of the synthetic instrument of associated risk assessment, allowing the identification of the level of risk, separately: methane, fire and combined,
- select a subset of longwalls similar with respect to the occurrence of associated risk,
- classification of longwalls into statistically homogeneous subsets, with simultaneous calculation of synthetic measure for each longwall, which enables assessment of the associated risks.

The results of calculations presented in this article with high probability reflect the actual level of associated risk in the evaluated set of 75 longwalls operated in Polish coal mines in 2011. The calculated value of the synthetic assessment measure of both risks enables us to rank these longwalls in terms of the level of risk.

The presented method for assessing the associated risks: methane and spontaneous fire, allows to perform a comparative analysis of co-occurrence of these risks in extracted longwalls.

The article was written in connection with the conduct of research and analysis during the implementation of stage 5 ent. “Development of Methods for Comprehensive Evaluation of Fire and Methane Hazard in Extraction Areas” *research task No. 2, ent.* ***“Development of Design Rules for Mining Works in Conditions of Associated Risk of Methane and Fire in Terms of Ventilation Systems in Underground Coal Mines”*** *within the framework of the strategic research project of the National Centre for Research and Development [Polish acronym: NCBiR] ent. “Improving Work Safety in Mines.”*

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Received: 10 June 2013