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PRACA DOKTORSKA

Zastosowanie wybranych modeli prognostycznych do przewidywania liczby wypadków na przykładzie kopalni węgla kamiennego

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SUMMARY

Poland is one of the main coal producing countries in Europe ($63 \cdot 10^6$ Mg in 2018, i.e. about 1% of the global supply and 83.5% of the EU supply) with 76,697 employees involved in coal mining tasks. Over recent 28 years (1990 to 2018), a remarkable reduction in the number of accidents has been observed which results from e.g. a decreased level of coal mining and employment in coal mines as well as from restructuring processes. The overall number of accidents was 16,515 in 1990; it dropped to 2896 cases in 2000 and, further, to 1372 accidents in 2018. Over this period, a nearly fivefold reduction in the fatal accident number and a nine-fold decrease in the number of serious accidents were reported (SMA 1990 to 2018). The overall accident incidence rate per 1000 persons employed in the coal mining industry between 2007 and 2017 ranged from 18.30 to 21.98 and the overall rate per 10^6 Mg yield ranged from 22.25 to 30.85. Based on the Statistics Poland data as well as the absolute and ratio analyses of accidents, a ranking list was developed where the “mining industry” is placed in a higher work accident risk group along with the “construction industry” as well as the “agriculture, forest, hunting and fishing sectors”. Specific characteristics of the mining industry are group accidents and disasters. Regarding these accident categories over the period of 2009 to 2018, the largest number of fatal accidents (24 workers) was reported in 2009, of serious accidents (29 victims) – in the same year and of minor accidents (86 victims) – in 2013.

At the beginning of the dissertation, selected representatives of the largest coal mining companies (), complex and simple (multi- and single-part) coal mines as well as plants that underwent ownership transformation are described.

Three following coal mines were selected to study:

- *KWK Mysłowice-Wesoła*: belongs to Polska Grupa Górnicza S.A., the largest coal producer in Poland and Europe (established as a result of fusion of, among others, *Kompania Węglowa S.A.* and *Katowicki Holding Węglowy S.A.*); currently a single-part mining plant with highly intensive natural hazards
- *KWK Budryk*: belongs to *Jastrzębska Spółka Węglowa S.A.*, i.e. the major producer of steam coal in Poland and Europe; a clear model of a new single-part coal mine and the youngest new mining plant in Poland (being constructed between 1978 and 1994); a modern mine with a development potential; highly intensive natural hazards

- *ZG Brzeszcze* – belongs to *Tauron Wydobycie S.A.*, i.e. an energy and mining concern; large restructuring processes (e.g. an independent coal mine, *Nadwiślańska Spółka Węglowa S.A.*, *Kompania Węglowa S.A.*, a mine being shut down); a modern mining plant with a development potential (level 900 m under construction); currently a single-part mine; highly intensive natural hazards

In the next chapter, legal bases regarding accidents at work are described. The subjects of analysis were selected occupational accidents (events at work, accidents of non-employees, accidents on the way to and from work) in the light of legal bases that define basic terminology and procedures for determining circumstances and reasons of an accident (accident protocol), e.g. when an event is deemed an accident, how to document accidents and how to award accident insurance benefits due to an accident at work.

Chapter 4 focuses on classifications of hazards and analyses of accidents at work where selected classifications of hazards and risks in the work environment (including specificity of coal mining industry) in the light of legal bases and source literature are analyzed. Moreover, the principles of accident at work statistic analysis (absolute, ratio, by-kind analyses) and classifications of accident rates in the coal mining industry (incidence rates, severity rates, risk rates) were analysed. Also, the principles of accident at work statistic analysis, classifications of retrospective analysis and its substantial description based on the absolute, ratio, by-kind and correlation analyses are presented. Accident rates are discussed regarding the mining industry, based on the following criteria: time, structure, statistical analysis (rates of structure, intensity and dynamics), accident rate analysis (rates of incidence, severity and risk).

The next chapter contains a description of the prognostic process where the basis, aim, function, methods and the horizon of prognosis are considered. Furthermore, the stages of prognosis mechanism and the measures of prognosis accuracy are discussed in detail because a complex process of decision-making includes several stages and should follow a pre-defined procedure. The most important stages are as follow: identification of a decision-making situation, designing selected variants, assessment of the variants being designed and, eventually, selection of one of the developed variants according to the assumed criteria. The final stage includes implementation of the specific decision and control of its effects.

In Chapter 6, selected prognostic models (a total of 25 model types) are presented in accordance with the process of future prediction and assessment that, according to the prognosis theory, is based on theoretical research, analytical considerations, logical backgrounds and practical experience where quantitative, statistics-related methods, probability mathematics and models being built are applied. The models selected describe quantitative relationships between ex-post variables where historical empirical data are the basis for estimation of stochastic parameters. To develop prognoses, 9 elementary (adaptive) models, 12 models of exponential smoothing, a linear model, a linearized model as well as the autoregressive model were selected.

Based on the considerations, the dissertation objective was formulated: the analysis of accidents at work statistics in selected coal mines based on official statistic data and accident predictions using selected prognostic models.

The analysis of accidents at work statistics in the selected coal mines has been conducted in Chapter 8 based on the statistical data gathered regarding accident rates in *KWK Mysłowice-Wesoła*, *KWK Budryk* and *ZG Brzeszcze*, according to statistical data of the State Mining Authority from the period between 2007 and 2018. The analysis of above data is presented as the absolute and ratio analyses for each mining plant. The ratio analysis was developed based on the following rates:

- the overall accident incidence rate per 1000 employees W_Z
- the overall accident incidence rate per 100 thousand working days W_D
- the accident severity rate per 1 injured person C_W
- the accident risk rate W_R
- the accident incidence rate per 1 million Mg mining yield W_T

Based on the overall accident incidence rate per 1000 employees, *Mysłowice-Wesoła*, *Budryk* and *Brzeszcze* coal mines were compared in terms of occupational safety, having summarized data for the mine and service companies employees. Between 2007 and 2011, the highest (and relatively high) overall accident incidence rates among the mines being compared were those for *KWK Budryk*. In 2012–2014, the highest rates were found for *KWK Mysłowice-Wesoła*, while during the other years – for *ZG Brzeszcze*.

The ninth and tenth chapter, refers to prognosis of accidents in selected coal mines based on 25 models as described in Chapter 6:

1. A model of naive method with the additive aspect for the time series with a development trend.
2. A model of naive method with the multiplicative aspect for the time series with a development trend.
3. A model of simple moving average.

4. A model of simple moving average for the time series shaping around a constant value (average) (k=2).
5. A model of simple moving average for the time series shaping around a constant value (average) (k=3).
6. A model of weighted moving average for the time series shaping around a constant value (average) (k=3).
7. A model of simple moving average for the time series shaping around a development trend (k=2).
8. A model of simple moving average for the time series shaping around a development trend (k=3).
9. A model of weighted moving average for the time series shaping around a development trend (k=3).
10. A model of simple exponential smoothing (for various starting mechanisms).
11. A model of single exponential smoothing (Brown's model).
12. A model of exponential autoregression (k=3).
13. A model of exponential autoregression (k=2).
14. Holt's linear model with the additive trend (for various starting mechanisms).
15. Holt's linear model with the multiplicative trend (for various starting mechanisms).
16. Holt's linear model with the effect of additive trend damping (for various starting mechanisms).
17. Holt's linear model with the effect of multiplicative trend damping (for various starting mechanisms).
18. Holt's quadratic model in the additive formula (for various starting mechanisms).
19. A method of Brown's double exponential smoothing for the linear model.
20. A method of Brown's triple exponential smoothing for the quadratic model.
21. An advanced model of exponential autoregression.
22. A model of creeping trend – prognosis using the method of harmonic weights.
23. Prognosis based on the linear model.
24. Prognosis based on the nonlinear model – linearization.
25. Autoregressive (AR) models.

Implementation of the algorithms of above models and related calculations were performed in the Excel program using its built-in functions, data analysis tools and the optimization tool. To achieve a maximum objective assessment of prognoses quality, it was based on the following criteria:

- K1: Ex-post error Ψ (equation 6.3) for the series with empirical data from the years 2007 to 2016.
- K2: Ex-post error Ψ (equation 6.3) for the series with empirical data from the years 2007 to 2018.
- K3: Ex-post error Ψ (equation 6.3) for the series with empirical data from the years 2017 to 2018.
- K4: The coefficient of variation for random variables *Ve* (equation 6.54) for ex-post prognoses regarding the years 2007 to 2016; except the linear and linearized models, the coefficients for all prognoses were estimated using the RMSE* value.
- K5: The coefficient of variation for random variables *Ve* (equation 6.54) for ex-post prognoses regarding the years 2007 to 2018; except the linear and linearized models, the coefficients for all prognoses were estimated using the RMSE* value.

All values of the errors and coefficients were standardized by dividing the result of subtraction of a specific value and the mean of all applied prognoses by the standard deviation value for each criterion.

For the summary assessment of a specific prognosis, the scoring method was used with the following weights:

- K1 and K2 criteria – 10% each
- K3 and K4 criteria – 20% each
- K5 criterion – 40%

In forecasting the total accidents considered and the Wz indicator, one universal forecasting method cannot be found. A model of creeping trend – prognosis using the method of harmonic weights and autoregressive AR model work well. Annex 2 contains algorithms for 25 forecasting methods. After entering the data and making small adjustments to the parameters, you can find the models with the best fit goodness in the "Criteria summary" sheet.

The last chapter concerns the formulated conclusions on the basis of the absolute and ratio analysis as well as the developed accident forecasts in selected mines. There is no universal prognostic method in forecasting the considered accidents in total and the W_z ratio. Harmonic balance methods and autoregressive models work well. On the basis of the conducted research, they were recommended models with the best goodness of fit.