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The accident rate in Polish mining. Current status and forecast

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Abstract
The article presents the analysis of accidents at work in the Polish mining industry in the period from 2010 to 2020 with forecasts for the next three years. The study consists of two parts. The first part deals with methods of analyzing working conditions in the mining industry. A key element of the literature review is the econometric methods that researchers have used to analyze accidents at work in mining. In the empirical part (the second part of the paper), the authors present the results of their own econometric analysis. The authors use econometric models in predicting the indicator (W*) – total number of people injured in accidents per thousand employees. Testing classical econometric models, the authors obtained the best forecasts (based on the obtained forecast errors) in Winters' model and Brown's model. The accident at work in mining is an important topic for research because the branch of industry belongs to the branch with hard work. Health and safety in mines have great importance for the sake of specific conditions in that kind of industry. Continuous analysis of accidents at work is necessary for the evaluation of system effectiveness of the health and safety system in all mines. Forecasting accidents at work can help miners to build safety in mines.

Keywords
accident at work, ratio analysis, mining and quarrying, health and safety

Introduction

Work safety is a key factor that determines the proper development of each economic activity, as there is a close relationship between human activity and the need for safety. In modern business, safety at work is an important element of the enterprise's policy and management system. Safety is improved by realized actions in enterprises (Abd Ali et al., 2021). Work safety measurements and assessments are mandatory and are the employer's responsibility toward employees. In a modern company, all employees, not just departments and health and safety managers, are responsible for safety (Niczyporuk, 1996). Organizations are created by employees (people), and their share in the improvement of work safety is growing year by year by initiating activities in the area of improving working conditions at specific workplaces. In safety management systems, employees' awareness is built to ensure that they perform their work safely and that they do not threaten their health and life and other employees' health and life. Safety management in the industry is a complex process in which material and technical working conditions are improved in parallel, and workers' awareness and commitment to safety are built. Occupational accidents most often occur due to Organizations are created by employees (people) and their share in improvement of work safety is growing year by year by initiating activities in the area of improving working conditions at specific workplaces. In safety management systems, employees' awareness is built to ensure that they perform their work safely and that they do not pose a threat to their health and life and to the health and life of other employees. An improvement of safety conditions in the industry is a complex process in which, in parallel with the improvements of material (technical) working conditions, an increase of the workers' engagement is required (Kopas, Blatnicky et al., 2017). Work injuries usually occur because safety rules are not applied or because of a lack of awareness, or for many other reasons (Kovanič et al., 2020; Kovanič et al., 2013; Shaawat et al., 2020; Urban et al., 2019). Such an approach is in agreement with the TQM philosophy in which total quality is a highly participative process for improvement (Kopas, Saga et al., 2017). In global economy, safety at work influences on employer, employee, his family, and society. In spite of the extremely important humanitarian aspect of the protection of human life, for the employer safety has, first of all, an economic dimension. This means safety is frequently interpreted as risk management. To assess this risk, accident rate analyses, concerning particular categories of accidents and their causes, are useful (Niczyporuk, 1996; Niczyporuk 1996a, Škvareková, 2021). Due to a high incidence of accidents, these analyses are especially important for the industry. Statistics from official organizations like the International Labour Organization (ILO) indicate that there is a death caused by work-related accidents every 15 seconds (Shaawat et al·, 2020).

The accident rate analysis plays a major role in risk management in mines. An accident at work is an element of the cost of the enterprise's operation. In analyses, the following classification is applied: minor accidents, serious accidents, fatal accidents, group accidents and individual accidents, total accidents. Considering particular types of accidents (Saga, Blatnicka et al., 2020), their causes are determined (Saga, Blatnicky et al., 2020). The accident causes are classified as follows: environmental and natural or geological conditions (e.g. rockburst; geological disturbance; protruding rock; lack of space;), technological - technology and machine (e.g. material defects, machinery and equipment defects, failures occurring in the course of operation machinery, equipment, devices, etc.); management (e.g. lack of or insufficient control of health and safety conditions; lack of or inadequate supervision of health and safety); work organization (e.g. lack of suitable team collaboration; lack of protection of machinery against its undesirable setting in motion, and people (e.g. entering forbidden areas, stress, inadvertence; inattentive work). A simplified classification of hazards and risks could be divided into three types natural, technical, and human (Sapietova et al., 2011). The natural conditions in underground mining, including fatalities in the mining industry with used technology and people behaviours, influence accidents in mining plants. Based on the research of Dan et al. (Dan et al., 2017), the influencing factors of coal mine workers' unsafe behaviours were divided into organizational, human-machine, and personal factors. The first category creates rules and regulations, education and training, and safety reward. The human-machine factor creates safety physiology and psychology, skill and knowledge. Workload, device, and working environment belong to the last category. The costs of mine accidents should be taken into account in the algorithms] of the costs of operating a mine, as well as when deciding on its closure. Authors Chmiela et al. (2022) proposed an example way of assessing mine decommissioning costs; it is worth modifying it with a module of incurred accident costs.

For purposes of the accident rate analyses, statistical data are applied. A period of historical analyses may be short-term (e.g., monthly, quarterly, half-yearly, yearly), medium-term (up to 3 years) and long-term (3 years and longer). Statistical data are helpful for historical analyses and predictions based on empirical data. Predictions of accident numbers can be modelled based on quantitative prognostic methods, which enable the determination of the event course over a specific time period, and the prediction results let us recognize possible future scenarios and select the optimal one (Zheng and Liu, 2009). While developing predictions, a couple of methods are applied: elementary, exponential smoothing, autoregressive, linear and linearized prognostic regressive models(Blišťan et al., 2019). Optimisation of the predictive value is based on a search for a minimum value of the selected error which is assumed to be its criterion (Saga et al., 2009). On the basis of statistical accident rate data from selected coal mines and using selected econometric models, a short-term prediction of the expected accident number in a selected industrial facility can be developed (Szeja, 1992).

The aim of this paper is to develop a short-term prediction of the overall work accident number in a selected industrial facility (a coal mine). The presented methodology can use to develop safety management. Prediction of the accident rate is a part of an important system element, i.e., risk management. The research introduction was a review of the literature and statistical data on the accident rates in the Underground Polish coal mining industry. The literature review was presented and described according to the primary research areas concerning the coal mining industry: key accident causes – reported and outlined in publications, areas and types of research conducted by scientists and their research methods. The above areas were identified based on the literature review (Muravev et al., 2019). The discussion section of the paper concerns the methodology of accident prediction in coal mines using the scoring method in the safety management systems from the perspective of the development of safety systems towards Industry 4.0.

The applied methodology is presented in Fig. 1. The investigations were preceded by analyzing the Polish mining industry's situation and the literature concerning statistical methods used for the accident rate analysis in coal mines by other authors.

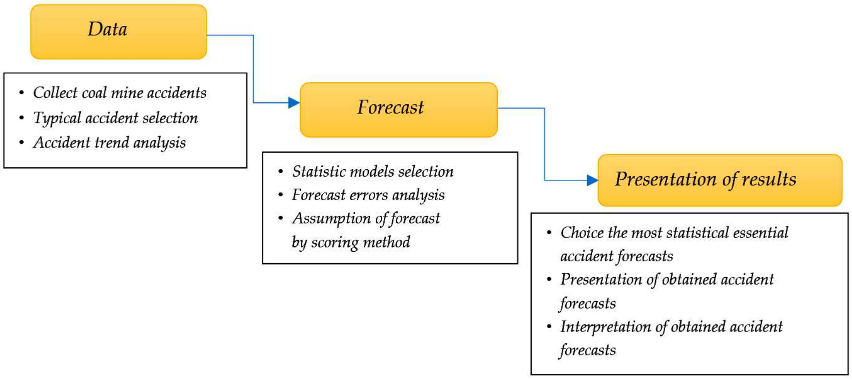

Fig. 1. Used methodology- analytical framework (source: own study)

Literature review

The accident rate concerning the coal mining industry worldwide is an important research issue due to the risks posed by coal mining activities. In terms of consequences of accidents in coal mines, gases pose the most hazardous risks (Wang et al., 2014), with methane explosions (Yin et al., 2017; Brodny et al., 2018; Krause and Smoliński, 2013; Tutak and Brodny; 2018; Trenczyk, 2015; Tutak and Brodny, 2016a; Tutak and Brodny, 2016b; Wang et al., 2017) and fires (Song and Kuenzer, 2014) in particular (Song and Kuenzer, 2014). In 2018, the coal production in Poland reached 63.4 million tonnes. At that time, approximately 916.1 million m^3 of methane were emitted (the overall methane emission, i.e., 1743 m^3 CH_4/min, including 1356.5 m^3 CH_4/min emitted during ventilation of mines) (Song and Kuenzer, 2014). The research topics mainly focus on supervision and regulation, risk management, evaluation, monitoring, and controlling technologies. Natural conditions vary among coal mining industries in particular countries. In addition to methane, strong effects of deposit availability and ecological conditions on accident rates in mines are observed.

Many research studies on accident rates are related to the human factor. The studies highlight the importance of human lives in coal mines (Mahdevari et al., 2014). Health problems mainly arise from the dust, gases, and noise generated during mining activities. Results of analysis – types of occupational hazards in categories: ergonomic, ecological, chemical, fire, physic, accident. The problems are continued risky behaviours of employees (Ruipeng et al., 2019) and the effects of working conditions on the miners' health (Mahdevari et al., 2014), with a special emphasis to be placed on the situation of Chinese employees due to the importance of this industry for the world economy and a high level of accidents in Chinese mines (Chen et al., 2012; Wang et al., 2019). Particular types of analysis regarding the effects of human factors on accident rates in mines are psychological studies on unsafe behaviours (Ruipeng et al., 2019; Wang et al., 2019a; Liu et al., 2012; Qiuao et al., 2018; Tong et al., 2019). Along with increased outlays on education and the number of training courses, miners' behaviours changes from unsafe to safe attitudes. It is clearly seen in long-term historical analyses (Yin et al., 2017). In safety management systems in coal mines, training and education of employees and managers plays a vital role in improving coal mine safety and is an important aspect of safety culture (Tlach et al., 2019). Training and education should be provided to new miners as well as experienced miners. Regular trainings are mandatory, while special courses should be conducted when miners change jobs or have a contract with new technological and geological conditions or new coal seams. All employees should attend training classes and be subjected to written and practical examinations of their acquired knowledge.

Research realized in Polish coal mines (Palka, 2017) shows that employees like new techniques of knowledge transfer, multimedia presentations, and stimulating teaching aids, but the identified problem was the incompatibility between theory and practice. Employees emphasized significant shortcomings in technical training in relation to modern machinery introduced into the company (Palka, 2017). The scientific community promotes psychological education to be more widely implemented because it can help miners learn how to understand their perceptions and make safe decisions (Liu et al., 2012). Such perceptions are important: 'I want to be safe' and 'You want me to be safe' (Guo and Wu, 2011). Finally, more and more safe behaviours of employees create a culture of safety. The culture is a fundamental building block in safety management. In the market economy, coal mines promote the concept of being 'people-oriented' rather than 'profit-oriented'.

During the literature review concerning countries (excluding Poland) to be analyzed in terms of accident rates in coal mines, China (He and Song, 2012), the USA (Sapko et al., 2006) and India (Lokhande et al., 2015) were found the dominating countries. In the literature (the WoS, Scopus scientific databases), analyses of the coal mining industry in Australia (Joy, 2004) and Turkey (Sari et al., 2001) were also found. The great interest in Chinese mines results from the importance of coal to the economy. The coal mine provides energy for many industries in the Chinese economy. In the country, coal is the primary source of industrial energy (Yongliang et al., 2017). According to the British Petroleum (BP) Statistical Review of World Energy 2016, China belongs to the countries whose coal production is the largest: 3,747 million tonnes. The second place belongs to the USA with a production of 813 million tonnes, and the third to India: with 677.5 million tonnes. According to the report, coal production in Poland only reaches 135.5 million tonnes (BP, 2016).

For comparative purposes, researchers analyze the accident rate data for the mining industries in China and the United States (Guo et al., 2011), e.g., the basic accident indicators (Nieto et al., 2014) and other data (Chen et al., 2013). Comparisons between the USA and China (Nieto et al., 2014; Chen et al., 2013; Feng et al., 2013) [43-45] also concern the evolution of accident rate models in the coal mining industry (Chen et al., 2014). Moreover, comparisons for three countries are applied: China, the USA (Nieto et al., 2014) and India (Singh and Tripathi, 2009), e.g., safety in Chinese mining in the period 2002-2010 based on a comparison of other counties (Chu et al., 2016; Yang et al., 2014). Certain analysis findings are worth mentioning to convey the significance of publications referring to the accident rate in China: "In the period from 2001 to 2010, the average fatality rate per million tonnes in China was 26.87 times that of the USA and 10 times that of India. China's mortality rate declined to 0.89 per million tonnes in the period 2002-2009 (82%). Over the same period, India's mortality rate per million tonnes fell by 72% and the US by 51%" (Chu et al., 2016).

Considering the analysis of accident rates in coal mines, individual researchers use simple or more complex methods of statistical analysis. In addition to the subjects of analyses, the research studies differ in the timeframes of statistical data and the methods of analysis. While publishing their research findings, the authors mostly highlight their practical application for risk assessment. A few methods that are used in accident rate studies regarding the mining industry are worth mentioning here: statistical analysis (example of research subject: gas explosion questionnaires and discussion panels for fix the role and importance of training for improving the safety and awareness of the technical staff in the mining plant (Palka, 2017) neural networks (topic: risk assessment (Deng et al., 2017; Ahmadi and Movahed, 2019), Monte Carlo simulation (example of topic: unsafe behaviour) and sensitivity analysis, to fix behaviour-based safety (BBS) (Ruipeng et al, 2019); case study (Sui et al., 2015) or historical analysis of accidents (Wang et al. 2011; Cheng et al., 2012); statistic interaction between natural condition in coal mines and risk of accidents (Sui et al., 2015) or regression logistic model (Paul, 2009); coupling analysis to study on the risk measurement (Liu et al., 2011), modelling of accidents (AL-shanini et al., 2014), analytic hierarchy process – AHP, e.g. in mine gas prevention system (Zhang, 2011); tree analysis (topic: gas and dust explosion in coal mines (Shi et al., 2018)); stochastic modelling of accident risks (Sari et. Al. 2009); analysis by using the rank (Kędzior, 2015), risk analysis and prediction of out-of-seam dilution in longwall mining (Bahri et al., 2014), fuzzy Bayesian network (research subject: risk assessment) (Li and Wang, 2019); estimation of accident frequencies through fuzzy logic (Dan et al., 2017); advanced data mining techniques (Qiao et al., 2018), simulation method (Xia et al., 2015) to test technological solutions and others (Liu and Li, 2014; Cheng, 2016). Popular methods are econometric (statistical) ones that are used to search for relationships between investigated factors of working conditions in coal mines and their effects on work safety in mines (Tutak and Brodny, 2018). The accident situations in the mining industry described by the authors are subject to critical assessment (Geng and Saleh, 2015), or they are evaluated in terms of positive changes based on the evolution of coal mine accident rate indicators (Liu et al., 2015). Researchers apply statistical methods for local analyses within one or several mines in a country (Mahdevari et al., 2014), (Szlązak et al., 2014) or for comparative analyses of the key mining industries worldwide (e.g. China and the United States) (Chu et al., 2016; Guo and Wu, 2011) or comparisons of one country to international conditions (Sari et al., 2001). Among the research studies on accident rates in the mining industry, there are analyses with widely formulated research objectives (AL-shanini et al., 2014; Chen et al., 2014) or pilot studies (Grayson et al., 2009) or case studies (Sui et al., 2015; Shi, 2013). Concerning scientific publications with a general subject, i.e., work safety in mines, their authors focus on risk assessment and risk assessment models (Cao et al., 2006), including theoretical conditions to be the basis for analyses (Liang et al., 2011). In the field of predictions, the scientific literature includes publications on modelling injured employees as a result of work accidents in mines (Paul, 2009; Bahri et al., 2014) and the usage of technologies in mines (Schatzel et al., 2006; Krog et al., 2006). The research is conducted for specific purposes, such as productivity (Chen et al., 2016) and capability (Liu and Li, 2014), improvement (Chen et al., 2016; Qing-gui et al., 2012; Kowalska, 2014; Pejic et al., 2013; Badri et al., 2013), also with an example of equipment used (Petrović et al., 2014). Labour productivity is commonly used in the coal mining industry as a general indicator of changes in the efficiency of the coal production process (Chu et al., 2016). Scientific databases contain publications on research regarding studies that are useful for improvement of mine environment monitoring (Zang et al., 2014) and for assessment of the effects of mines on the environment by environmental implications (Sui et al., 2015; Chen and Feng, 2013; Sztekler et al., 2016). Monitoring of work conditions in mines markedly influences workplace accident prevention by controlling primary parameters of mine environments (Zhang, 2011; Yang et al., 2014; Thakur, 2018; Cheng and Yang, 2012; Chang, 2016; Szlązak et al., 2017; Szlązak et al., 2016; Chang, 2018).

Method of Analysis

For the purposes of the study, a three-stage method of own work was adopted. As part of the first stage, statistical data was compiled on: employment in the mining and quarrying industry, the number of people injured in total accidents, the number of people injured in severe, fatal and other accidents (Klarák et al., 2022), and data on days of inability to work due to accidents.

In the second stage, the absolute analysis of accidents at work and the ratio analysis were performed based on the data compiled in the first stage. As part of the second stage, the basic characteristics of descriptive statistics were also determined, such as maximum and minimum value, arithmetic mean, and standard deviation. The coefficient of variation V_e was also determined for the purpose of interpreting the obtained results. The following limits were adopted for the interpretation of the determined coefficient: low variability – $V_e < 25\%$, moderate variability – $25\% \geq V_e < 45\%$, mean variability $45\% \geq V_e < 65\%$ and high variability $V_e > 65\%$ (Małysa and Gajdzik, 2021).

The third stage consisted of determining ex-ante forecasts for the number of people injured in total accidents (collective approach to the problem) and assessing the trend of changes. The determined forecasts were also used to determine the value of the accident frequency index in total per 1000 employees and to determine the trend of changes (Kuric et al., 2022). In the prediction process, assumptions were made that the values of ex-post forecast errors should meet the following conditions: the value for mean error should be lower than 10%, while Rot Mean Square Error should be lower than the standard deviation S_e (RMSE < S_e) (Małysa, 2022; Snarska, 2005). Mathematical relationships allowing for the determination of indicators and the values of ex-post forecast errors are summarized in the Material and Method chapter.

Material and Method

Investigating accidents at work is an important element related to determining the directions of activities in the field of improving safety in the mining quarrying industry in Poland. The authors of the study analyzed the statistical data of the Statistics Poland on the accident rate in the Polish Classification of Activities section – "mining and quarrying" in 2010-2020 (Statistics Poland, 2010-2020). This section covers the mining of hard coal and lignite, mining of crude oil, mining of metal ores, other mining and quarrying, and mining support services (Burduk et al., 2021). These studies enable the implementation of the assumed work goal, which was safety assessment and determining the directions of activities in the occupational health and safety field for the industry in question (Handrik et al., 2017). In line with the adopted method, data was compiled on the number of people employed, the number of people injured in total accidents, the number of people injured in serious accidents, fatal and other accidents, and the number of days of non-compliance to work as a result of registered events. A collective summary of data is presented in Table 1.

Tab. 1. Statistical data on accidents at work in the mining and quarrying in Poland in 2010-2020 (Statistics Poland, 2010-2020)

Specification	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Number of people employed	175,200	173,900	175,800	170,200	161,300	150,100	140,300	135,300	134,200	135,400	130,500
Total number of people injured in accidents	3,175	2,908	2,687	2,393	2,298	2,261	2,204	2,200	2,244	2,407	1,994
Number of people injured in fatal accidents	26	29	26	18	25	16	27	11	18	20	14
Number of people injured in severity accidents	24	21	12	14	28	15	9	10	16	10	11

Number of people injured in an accident with another effect	3,125	2,858	2,649	2,361	2,245	2,230	2,168	2,179	2,210	2,377	1,969
Day lost	219,422	206,521	203,166	178,150	174,766	181,841	175,962	180,549	175,909	182,101	154,450

The compiled statistical data of the Statistics Poland (Główny Urząd Staytsyczny) were analyzed, and on their basis, accident rates were determined, allowing, inter alia, to compare enterprises with each other and industries (Małysa and Gajdzik, 2021). For the purposes of the study, the indicators of severity and frequency of accidents were determined, which are described in Table 2.

Tab. 2. Determined measures of accidents - indicators of severity and frequency of accidents (Szlązak et al., 2016)

Accident rate	Mathematical relationship	Explanation of symbols used
Total accident rate indicator (*W1*)	$W_1 = \frac{W}{Z} \cdot 10^5$	W – number of workers injured as a result of the accident Z – number of employed or working people W_s – number of workers injured in severity accidents W_f – number o workers injured in fatal accidents D_l – total work absence caused by the accidents
Frequency rate indicator of severity accidents (*W2*)	$W_2 = \frac{W_s}{Z} \cdot 10^5$	
Frequency rate indicator of fatal accidents (*W3*)	$W_3 = \frac{W_f}{Z} \cdot 10^5$	
Accident severity rate reduced by the number of fatal accidents (*W4*)	$W_4 = \frac{D_l}{W - W_f}$	

The performed accident analysis was detailed with the forecasting process with the use of selected econometric models, i.e. the Winters'model and Brown's model. Based on these models, ex-ante forecasts for 2021-2023 have been determined. The forecasting process does not end with the designation of forecasts; ex-post forecast errors were determined (Table 3). The analysis carried out in the study of accident rates and the forecasting process allowed for the determination of the directions of activities in the field of occupational health and safety for the mining and quarrying industry in Poland.

Tab. 3. Forecast errprs ex post (Snarska, 2005; Cieślak, 2001; Małysa, 2022)

Forecast error	Mathematical relationship	Explanation of symbols used
Mean error Ψ	$\psi = \frac{1}{n-m} \sum_{t=m+1}^{n} \frac{\lvert y_t - y_t^* \rvert}{y_t}$	n – number of elements of the time series m – number of initial time moments t y_t – empirical data y_t^* – forecasts value
Root Mean Square Error *RMSE*	$RMSE = \sqrt{\frac{1}{n-m} \cdot \sum_{t=m+1}^{n} (y_t - y_t^*)^2}$	
Standard deviation S_e	$S_e = \sqrt{\frac{1}{n-2} \cdot \sum_{i=1}^{n} (y_t - y_t^*)^2}$	

Results and analysis

From 2010 to 2020, the total number of people injured in accidents changed from 3,175 injured in 2010 to 1,994 in 2020. Changes in the total number of people injured in accidents also result from changes in the employment structure (Table 1). The number of injured persons in total accidents was characterized by a low variability of V_e = 12% (Table 4). From 2010 to 2017, there was a downward trend in the number of victims; in 2018-2019 an increase and then a decrease in 2020. This decrease may also be related to the occurrence of the SARS-COV-2 virus, which will significantly affect the functioning of enterprises, including mining industry companies.

The number of workers injured in fatal accidents was characterized by a moderate variability of V_e = 29%. The highest number of people injured in fatal accidents was registered in 2019 (29 people injured in fatal accidents), while the lowest value was recorded in 2017 (11 people injured in fatal accidents). There is no tendency in this type of event - increase and decrease in the number of people injured. The number of people injured in serious accidents was characterized by a moderate variability of V_e = 41%. The highest value of the number of people injured in serious accidents was registered in 2014 (28 people injured in serious accidents), while the lowest value was in 2016 (9 people injured in serious accidents). The number of people injured in serious accidents is characterized by a decreasing trend until 2012. Then an increase is recorded until 2014, a decrease until 2016, an increase in 2017-2018 and then a decrease and an increase – no trend. The most frequently recorded events in the mining and quarrying sector were other accidents (not resulting in long-term absenteeism). The number of people injured in other accidents was characterized by a moderate trend of V_e = 28%, in line with the assumptions adopted in "Material and Method". The highest value of the number of people injured in other accidents was registered in 2010 (3,125 injured people), and the lowest was in 2020 (1,969 injured). These events in the time period covered by the analyses were characterized by a downward trend in 2010-2016, an increase in 2017-2019 and then a decrease in 2020.

Tab. 4. Characteristics of descriptive statistics (own elaboration)

Specification	Min	Max	Average	Deviation standard	Coefficient of variation *Ve*
Number of people employed	130,500	175,800	152,927.27	18,618.81	0.12
Total number of people injured in accidents	1,994	3,175	2,429.18	356.68	0.15
Number of people injured in fatal accidents	11	29	20.91	5.99	0.29
Number of people injured in serious accidents	9	28	15.45	6.29	0.41
Number of people injured in other accidents	1,969	3,125	2,397.36	343.05	0.28
Number of days of professional absence of employees	154,450	219,422	184,800.91	18,070.01	0.09

Based on the statistical data presented in Table 1, the accident rate measures were determined, i.e., the frequency indexes (*W1-W3*) and the severity index (W4). The total accident frequency rate per 1,000 employees (*W1*) was characterized by a low variability of V_e = 6%. In the years 2010-2013, a decreasing tendency is recorded, and from 2014 to 2019, an increasing tendency. However, in 2020 there was a decrease (Table 5). The rate of serious accidents per 100 thousand employees (W2) was characterized by a moderate variability of V_e = 27%, in accordance with the adopted method specified in "Material and Method". The highest value of the indicator was registered in 2014 (*W2* = 17.4), and the lowest in 2016 (*W2* = 6.4). The rate of fatal accidents (*W3*) was characterized by a low variability.1). The accident severity index (*W4*) was characterized by a low variability of V_e = 16%. The highest value of V_e = 19%. The highest value of the indicator was registered in 2016 (*W3* = 19.2), the lowest in 2017 (*W3* = 8 was recorded in 2017 (*W4* = 71.1), while the lowest in 2011 (*W4* = 42.0).

Tab. 5. The values of the W1-W4 accident rates along with the characteristics of descriptive statistics (own elaboration)

Adopted measures of accidents	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
W1	18.1	16.7	15.3	14.1	14.2	15.1	15.7	16.3	16.7	17.8	15.3
W2	13.7	12.1	6.8	8.2	17.4	10.0	6.4	7.4	11.9	7.4	8.4
W3	14.8	16.7	14.8	10.6	15.5	10.7	19.2	8.1	13.4	14.8	10.7
W4	43.1	42.0	49.6	56.4	51.1	64.4	52.8	71.1	60.4	55.7	63.5

Adopted measures for accidents	Min	Max	Average	Deviation standard	Coefficient of variation *Ve*
W1	14.1	18.1	15.94	1.07	0.07
W2	6.4	17.4	9.97	2.77	0.27
W3	8.1	19.2	13.57	2.61	0.19
W4	42.0	71.1	55.46	8.98	0.16

The data analysis was carried out on historical data. Therefore, a prediction process was carried out, allowing for the assessment of future accidents. Therefore, forecasts for the years 2021-2023 have been set in order to assess the trend of changes (Kuric et al., 2021). Based on the analyses, it is stated that the number of people employed in the mining and quarrying sector will decrease compared to 2020, and this decrease is forecast for the years 2022-2023. The values of ex-ante forecasts were determined on the basis of the Winters' model with a multiplicative trend and multi-session nature, with the coefficients $\alpha = 0.32$, $\beta = 0.01$ and $\delta = 0.01$. The values of the parameters α, β and δ were determined using the Solver tool and minimizing one of the ex-post forecast errors, i.e. mean error (Wiecek et al., 2019).

In the case of the total number of people injured in accidents, an increase is recorded (2021) and a decrease in the years 2021-2022. The increase in the number of people injured in 2021 does not constitute a good forecast for the industry in question, with a large number of people employed, in line with the forecasts (Table 6).

Tab. 6. Ex ante forecasts for 2021-23, forecast errors and model parameters (own elaboration)

Specification	2021	2022	2023	Designated ex-post forecast errors			Model parameters		
				ψ [%]	*RMSE* [-]	S_e [-]	α	β	δ
Number of people employed [thousand] (Winters' model with a multiplicative trend and multiplicative seasonality)	12.97	9.84	8.80	2.7	0.53	0.66	0.32	0.01	0.01
Total number of people injured in accidents (Brown's double smoothing model)	2,035	1,973	1,911	8.4	228.7	259.3	0.33	-	-

The forecasts were made using the double-smoothing Brown's model. The value of the parameter $\alpha = 0.33$ was determined with the use of the Solver tool, and the mean error minimization criterion was adopted. On the basis of the analyses carried out, it is stated that an important element is taking pro-safety measures to limit the number of accidents recorded in the mining and quarrying industry industry (Kuric et al., 2020).

Based on the data presented in Table 6, the total accident rate indicator per 1000 employees (*W1**) for the years 2021-2023 (Table 7) was determined. The determined values of the indicator (*W1**) show a diverging trend. The highest value of the *W1** indicator was recorded in 2023 (*W1** = 21.7). In the years 2020-2023, we can talk about an upward trend, which is not positive information for the industry in question. A graphic summary of the data on the *W1* indicator (Table 5) for the years 2010-2020 and the indicator values determined on the basis of the data presented in Table 6 are shown in Fig. 2.

*Tab. 7. Total accident rate indicator W1**

Specification	2021	2022	2023
Total accident rate indicator *W1**	15.7	20.1	21.7

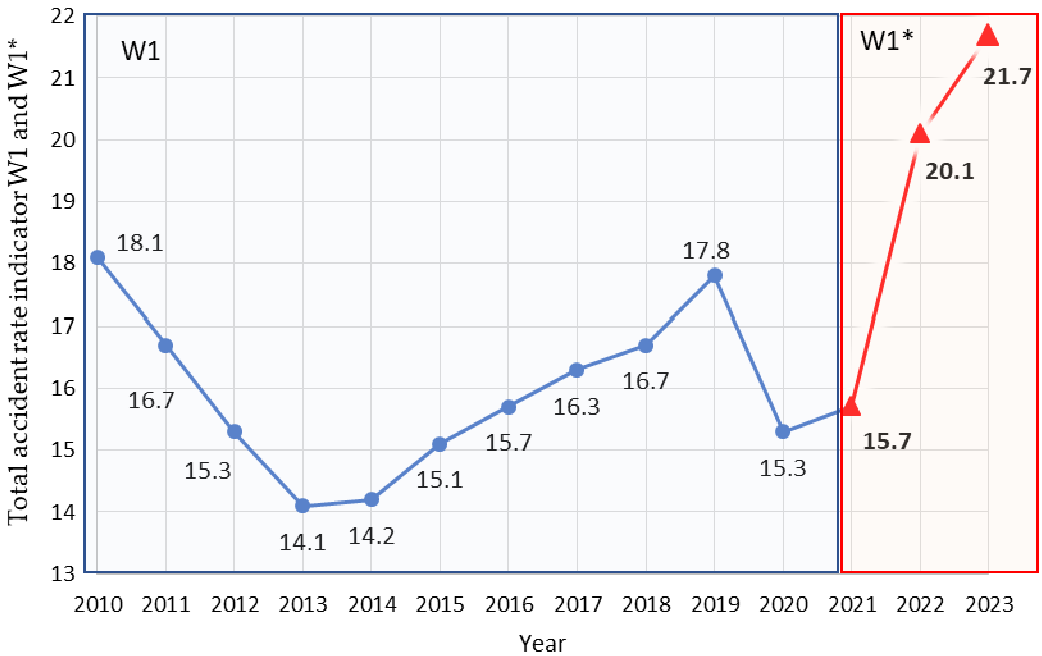

Fig. 2. Total accident rate W1 with forecasts for 2021-2023 (W1)*

Discussion

The care of safety at work in coal mines has been a component of certified management systems for the last twenty years. They are contained in the safety management systems, including risk management. The systems of work safety in coal mines will evolve towards Industry 4.0. The occupational health and safety management system exist as an element of the integrated management system along with the quality and environmental management systems. The ways of functioning of integrated management systems in coal mines are consistent with overall assumptions of the systemic approach to enterprise management, and its structure is created by mutually related documents, from the organizational policy and strategy (Niu, 2014) to operational activities, including the set of instructions and procedures and (Ochman, 2011) integrated actions at all organizational and supply-chain levels.

The safety of work in coal mines is a component of a widely defined sustainable development strategy. Nowadays, sustainability is a commonly required paradigm of organization management and business conduct. Each mine may determine its own path toward sustainable production and performance (Xie et al., 2013; Nawrat, 2012), giving priority to safety at work protection on the way to sustainable coal mining (Małysa and Gajdzik, 2021).

In recent years, improvements in coal mine machinery performance have been implemented, e.g., through the Overall Equipment Effectiveness (OEE) analysis (Stecuła and Brodny, 2016) as part of the Total Productive Maintenance (TPM) application (Brodny et al., 2016). In a coal mine, specific goals in the form of Key Performance Indicators (KPIs) are determined for each unit and department. In the areas of machine control techniques and data transfer, huge progress has been observed. Sensors for data collection, device control, monitoring of device operating parameters and, even more importantly, work environment monitoring have been introduced. The control systems, combined by means of communication modules for controllers, ensure real-time observation of machinery operations as well as monitoring of the work environment, and the set alert thresholds communicate deterioration of the working conditions. In practice, despite the use of modern monitoring systems for the state of the underground environment and the use of modern machines, human errors are the most common cause of all types of accident events (Matuszewski, 2009). The aim is to improve both the safety of people operating the machines and the efficiency of the machine (Stecula and Brodny, 2016).

With the popularisation of Industry 4.0, one of the main areas of change is the practical use of IT systems to optimize and control production processes. Widespread digitalization is resulting in the emergence of cyber-physical systems, which, alongside the Internet of Things, are beginning to be used more widely in many industries that cooperate with coal mining, e.g. steel industry (Gajdzik and Wolniak, 2021a; Gajdzik and Wolniak, 2021c). New technologies are also being applied in mining, including in the Polish coal mining industry (Szurgacz and Brodny, 2019). Implementation of new technologies needs companies' cooperation in the supply chain and building trust between them (Grzybowska and Gajdzik, 2012). The steel sector should be an active participant in the supply chain because coal is still needed by economies.

Application of both the radio frequency identification (RFID technique) to improve safety management system) (Xu et al., 2015), using wireless sensor network (WSN) to monitor the temperature, humidity, gas, and status of smoke in underground mines (the widespread use of various types of sensors to monitor the condition of the atmosphere in the mine – the sensors form large systems to automatically warn the employees of risks/hazards in specific areas); establishing a Web of Things-based remote monitoring system for coal mine safety; employing Cable Monitoring System (CMS) and the WSN to build an integrated environment monitoring system for underground coal mine, and the Internet of Things (IoT) and Cloud Computing (CC) (Sun et al., 2012), are built in the systems of working condition monitoring and accident prevention in coal mines (the prealarm system). In the process of implementing Industry 4.0 changes, there is no one-size-fits-all path to follow; each industry must choose its own way of being in Industry 4.0. The investment projects implemented must be driven by the industry's development strategy and internal management decisions (Gajdzik et al., 2021).

In addition to these solutions, predictions and modelling of work safety have become increasingly important in modern mines. Arduous working conditions, many risks, and hazards, as well as the variety of mining technologies, oblige the executive staff of mining companies to improve the work safety management system continuously. The method of workplace accident predictions in coal mines with the scoring method mentioned in this paper may constitute the basis for developing an IT algorithm aiming at improvements in the process of work safety management. Prediction and scoring models enable a thorough assessment of the accident risk, the use of prediction models for improved mining prevention (to predict accidents along with their causes) and assessment of the accident probability with a relatively high prediction strength (Gini coefficient of approx. 80%).In addition to our methodology, valuable sources of information are the other methods of working condition assessment in coal mines (mentioned in the literature section) that are precisely and thoroughly outlined by the authors in their publications. Any of these descriptions, along with a presented example of calculations and/or a case study, may be used for the development of a set of useful methods for the risk analysis and assessment of accident rates in coal mines. Assuming distant long-term decisions to be made by the top management, IT and computer solutions (specific computer applications) for improvement and facilitation of decision-making processes seem to be particularly useful.

Conclusions

The issue of accident rates in the mining and quarrying industry is an important scientific and practical issue. Based on the conducted analyses, it was found that:

- the total number of people injured in accidents was characterized by a decreasing trend; however, on the basis of the forecast forecasts, in 2021, an increase in the total number of persons injured in accidents can be recorded. This information is not beneficial to the industry in question:
- other accidents dominate the mining and quarrying industry. An important element, however, is the implementation of effective prevention in the field of limiting these events – technical and organizational solutions. Effective in this respect may be the implementation of the employee suggestion system;
- severe and fatal accidents generate significant costs for the subject. Due to their severity, the causes of these events should pose a significant problem in the implementation of effective preventive prophylaxis;
- performing absolute and index analysis, as well as the use of forecasting, enables more complete analyses related to occupational safety in the industry in question.

The conducted own research made it possible to assess occupational health and safety in the mining and quarrying industry. Based on the conducted analyses, fluctuations in the number of people injured in accidents at work are recorded. The specific working conditions and the occurring natural hazards may make it difficult to eliminate them entirely. Therefore, an important element is effective prevention, health and safety analysis, continuous monitoring of working conditions, as well as the use of modern methods and solutions to reduce the risk of accidents. The authors' forecasts of accidents in the Polish mining industry can be presented as a case study or can be used for further scientific research. The authors propose identifying accident factors, ranking them and applying AHP (*Analytic Hierarchy Process)* analysis. The authors Gajdzik et al. (2018) used such a method for forecasting in the steel industry. The model presented covered the period 2010-2023, of which the last three years are forecasts. One would have to wonder if the models presented were influenced by the economic crisis caused by the restrictions due to COVID-19. As studies show, declines in production were recorded at that time (PAP, 2021). Production declines affected many coal-based supply chains, including the steel sector (Gajdzik and Wolniak, 2021b). So, when coal mining fell, did accidents fall? This question will be addressed in further research. Furthermore, referring to the discussion presented on the importance of Industry 4.0 technology for improving working conditions, the authors propose to develop a model of the impact of Industry 4.0 (I 4.0) technology investments on accident rates, as Gajdzik and Sroka (2021) did when analyzing the impact of I 4.0 investments on resources intensity, this time the parameters for assessing accidents at work can be used.

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