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PRODUCTION ENGINEERING ARCHIVES 2024, 30(1), 67-74

PRODUCTION ENGINEERING ARCHIVES

ISSN 2353-5156 (print)
ISSN 2353-7779 (online)

Exist since 4th quarter 2013
Available online at https://pea-journal.eu

The impact of employment restriction on the risk of an accident at work in the mining industry in Poland

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Article history
Received 22.10.2024
Accepted 11.01.2024
Available online 29.02.2024

Keywords
Relative risk (RR),
Accidents at work,
Employment,
Mining industry,
Poland.

Abstract
The European Union's energy policy has necessitated a reduction in coal mining, with significant consequences for occupational safety within the industry. This study investigates the correlation between employment reduction and accident risk within Poland's mining sector during 2006-2020, a period marked by over a 40% decrease in coal extraction and a corresponding 30% decrease in mining employment. An escalation in the relative risk (RR) of accidents was observed, increasing from 1.28 to 2.33. More critically, the RR of fatal accidents rose from 2.54 to 8.22 by 2019. Analysis revealed a critical employment threshold: a fall in mining employment below 140,000 is associated with a marked increase in accident risk, particularly fatal accidents. A linear model was developed to suggest that a reduction in the RR of accidents to 0.7 is requisite to achieve a national average risk for fatal accidents (RR = 1). The findings advocate for targeted safety interventions and propose a preventive strategy model. The implications are vital for policymakers and industry stakeholders aiming to improve worker safety in response to employment changes within the mining sector.

DOI: 10.30657/pea.2024.30.6

1. Introduction

The issue of accidents is an important issue in the field of occupational health and safety. Every day, employees suffer accidents at work, which is why protection against their negative effects becomes so important. Employers implement preventive solutions that improve safety, however, expenses at work are still registered. The mining industry is classified as a hazardous industry due to the nature of the work performed, as well as the occupational hazards involved. Therefore, it is the subject of scientific research (Brodny et al. 2018; Škvareková, 2021; Wang et al., 2011; Saleh et al., 2011). Studies pay special attention to methane hazards and the designation of hazardous zones, the use of solutions to improve the organization of work, or analyses aimed at formulating measures to prevent accidents at work.

When organizing work to ensure safe working conditions for employees, the employer must take into account a number of factors, which can be administrative and legal requirements, environmental and organizational conditions. Production-stabilized, repetitive processes should not be a problem for the employer to maintain the established level of safety. The problem can be processes in which organizational changes, such as downsizing, occur in an unchanging work environment. Particularly in the mining sector, such change can cause even proportional reductions in staffing in the supervisory and laborer divisions to result in an uncontrolled increase in the level of hazards. This increase can be caused by insufficient monitoring of hazards resulting from staff reductions in the control and maintenance divisions.

Restructuring of the mining sector in Poland (Chmiela et al., 2022), carried out in recent years, is a good example for case study analysis, changes in the risk level as a function of reduced employment and mining in hard coal mines. The aim of the article is to assess the relative risk (RR) in the field of accidents at work registered in the mining sector in Poland in terms of taking actions aimed at improving occupational safety.

2. Literature review

The issue of investigating accidents at work is important from the point of view of scientific research and has practical significance for employers. The definition of an accident at work is different in each country. The differences that occur relate to harm, harm or loss. However, there is agreement on

the suddenness and external cause (Szlązak et al., 2012). Only events that meet the definition of an accident at work entitle the injured party to accident benefits. In the literature, the authors examine accident events recorded in the mining industry (Chu et al., 2016; Chen et al., 2013), thus emphasizing the essence of the issue and the need to implement solutions aimed at effectively reducing the occurrence of accidents at work and the exposure of employees to the factors occurring in the work environment (Table 1).

Table 1. Topics and directions of research in the field of occupational health and safety for various industries

Authors	Topics of conducted research
Chu et al., 2016	The issue of accidents at work, occupational diseases and their impact on the environment. The authors also draw attention to the role of occupational risk assessment on work safety in mining
Chen et al., 2013	Issues related to threats related to gas explosions. Investigation of the causes of accidents at work - direct and indirect causes. The role of the human factor in recorded accident events in hard coal mines
Škvareková et al., 2021	The role of increasing employees' attention while performing professional activities and during work related to the transfer of materials and heavy objects
Brodny et al., 2018	The research aimed to analyse the functioning and designate zones of the ventilation system where methane concentrations that are dangerous for employees may occur
Joy, 2004	Issues of the approach to risk assessment and presentation of the reactive side of risk management, accident and incident investigation in the mining industry
Ignac – Nowicka et al. 2015	Analysis of accident statistics in the mining industry. Analysis of mining factors on the health of employees

The conducted research concerns the occurrence of occupational hazards (Brodny et al., 2018), accidents at work (Chen et al., 2013), occupational diseases (Ignac-Nowicka et al., 2015), the role of occupational risk assessment, which is part of the protection of the employee and the environment (Chu et al., 2016; Joy, 2004), as well as the activities performed by the employee while working (Škvareková et al., 2021). The analyses conducted concern important issues for the mining sector in various countries. Thanks to the conducted analyses, it is possible to evaluate the implemented solutions as well as preventive measures aimed at improving occupational safety. This study supplements the analyses carried out in the field of health and safety issues for the mining industry with the possibility of determining the relative risk RR, which allows to determine how the structure of employment in the industry in question affects the number of registered accident events.

In Poland, according to the legal classification, the "mining and quarrying" industry includes mining / underground mining, opencast or drilling, minerals occurring in nature as solids (coal and ores), liquid (crude oil), or gaseous (natural gas).

The mining sector in Poland is primarily hard coal mining. According to a report by the Institute for Structural Research (Sokołowski et al., 2022) the majority of people working in mining are aged 15-39 (49% of employees). 33% of the employed are people aged 40-49, 16% aged 50-59, and 2% aged 60 and more. In 2019, the average age of a mine worker was 36 years, and the average age of a surface worker was 48 years. The workers working underground were 36 years old on average, and the supervising were 40 years old. Under sectoral agreements, men in the mining industry are entitled to a retirement age after reaching 50 years of working for a minimum of 15 years underground and 10 years in an equivalent job, while women may retire after 15 years of underground work and 5 years of equivalent work to mining. The pension is unconditionally due after 20 or 25 years of work experience in mining.

Climate change and energy transformation mean that Poland has to look for alternative fuels in order to reduce coal combustion. According to the arrangements resulting from the agreement between the trade unions and the government, the last hard coal mine in Poland is to be closed in 2049. Employment and mining are reduced in accordance with the agreed schedule, and these changes in 2006-2020 are graphically presented in Fig. 1. During this period, employment was reduced from 181 to 127 thousand people.

Working in the mining sector, regardless of whether it is an opencast or underground mine, is associated with a much greater risk than in most sectors of the national economy. This is evidenced not only by the number of accidents at work but above all by the severity of injuries, quantified e.g., as the number of days of inability to work. A high risk of accidents is related to the simultaneous exposure of workers to technical and natural hazards related to the exploitation of the rock mass, e.g., the risk of rock bursts, gas or water. Among the significant identified accidents in mining, methane explosion, coal dust explosion, flooding, collapse, fire and traffic accidents, respectively, constitute the highest levels of risk (Bagherpour et al., 2014; Chu et al., 2016). Due to the dynamics of phenomena occurring in mines, great emphasis should be placed on organizational and early warning systems (An, 2012).

In connection with the above, the legislator in Poland for the mining sector, in addition to the generally applicable health and safety regulations, has published detailed regulations relating to the operation of mining plants. Despite the strict requirements and specific procedures in force in the sector, numerous accidents at work are registered each year, including fatal and collective accidents. Presented in tab. 1. Accident data show a decreasing number of people injured in accidents at work in 2006-2020 by approx. 30%, including serious accidents by approx. 45% and fatal accidents by approx. 50%. At that time, employment reduction in the sector amounted to approx. 30% (Fig. 1).

The drop in the number of people employed in the mining sector by over 30%, with an increase in the number of employees in Poland by approx. 20%, resulted in a change in the percentage of people employed in mining (2.4% in 2006; 1.4% in 2020). Along with the reduction of employment in

the mining industry, the percentage of people injured in accidents at work in this sector increased in national terms (2.59% in 2014, and 3.18% in 2020). This proves the increased risk of an accident at work in the mining industry as compared to the entire national economy. Therefore, the aim of the research was to analyse the relative risk (RR) of an accident at work in the mining sector in Poland in 2006-2020 and to determine the limit number of people employed in the mining industry, above which the risk of an accident increases.

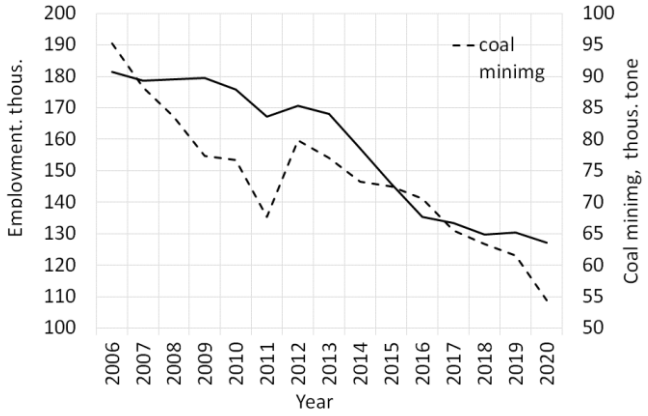

Fig. 1. Hard coal mining and employment in the mining industry in Poland in 2006-2020

3. Research methodology

The research was conducted on the basis of statistical data on the number of people injured in accidents at work and the number of people employed in the mining industry (Fig. 1, Table 2). The data is collected and published in the annual reports of Statistic Poland (Statistic Poland, 2022).

The research used the following methods: Relative Risk (RR). The RR was determined by Equation (1). Determining the relative risk value requires calculating the probability of a given event occurring in two groups (the study group and the reference group-control). In the literature, relative risk (RR) is determined, among others, to assess the incidence of a specific disease (Bruner et al., 2003; Sun et al., 2016; Li et al., 2012, Altobelli et al., 2020), or also to analyse data statistics on accident rates in various branches of the economy (Nowacki, 2021; Małysa, 2023), and road traffic expenses (Vaa, 2014). This study refers to the study of accident rates in the mining industry in Poland, with reference to analyses to determine how the occurrence of accident events in mining relates to events occurring in the national economy (larger / smaller).

$$RR = \frac{Q_{11}/(Q_{11}+Q_{12})}{Q_{21}/(Q_{21}+Q_{22})} \quad (1)$$

where:
Qij – multiplicity observed in the contingency table (i – column; j – row in the contingency table, in this case, a two-way table).

Table 2. Victims of accidents in the mining industry in Poland in 2006-2020 (Statistic Poland, 2022)

Year	Victims of accidents		
	total	serious	fatal
2006	2928	21	29
2007	3173	32	26
2008	3156	25	31
2009	3096	41	41
2010	3175	24	26
2011	2908	22	28
2012	2687	12	27
2013	2393	14	18
2014	2298	28	25
2015	2261	15	16
2016	2204	9	27
2017	2200	10	11
2018	2244	16	18
2019	2407	10	19
2020	1994	11	14

The following hypothesis was adopted: null hypothesis that H0: RR = 1 and the alternative hypothesis that H1: RR ≠ 1. To verify the hypothesis that the risk of occurrence of the phenomenon under study is the same in the exposed group and in the group not exposed to the risk factor, the test statistic was expressed as (2).

$$Z = \frac{ln(RR)}{SE} \quad (2)$$

where:

$SE = \sqrt{\frac{1}{Q_{11}} - \frac{1}{Q_{11}+Q_{12}} + \frac{1}{Q_{21}} - \frac{1}{Q_{21}+Q_{22}}}$ – standard error of the logarithm RR.

As the data covered one country and the same group of employees, a joint effect was presented for the collected data by determining the fixed effect. The data were subjected to meta-analysis determining, due to the cohort nature of the research, for individual years and for the entire analysed period, as the final effect, the relative risk (RR) related to the occurrence of an accident at work in relation to the analysed range.

- Mann-Whitney test,
- Kendall test.

In each case, in order to determine the statistical significance of inference, the value of the p statistic was determined, assuming the significance level a = 0,05.

The limitations of the conducted research were the narrowed scope of the analysis based on available statistical data for one country, as well as the specificity of the mining industry in Poland.

4. Results and discussion

4.1. The risk of an accident at work in the mining industry vs the number of employees

The values of the relative risk in the mining sector in Poland determined according to the formula (1) together with the confidence intervals for the years 2006-2020 are presented in Fig. 2. Based on the obtained results, it was found that in the analysed period the risk of an accident at work in the mining industry was 1.55 times higher (RR [95% Cl] = 1.55 [1.54-1.57]) than for workers in other sectors. Since 2014, a progressive increase in the risk of an accident at work in the mining industry has been observed. The maximum value of RR [95% Cl] = 2.33 [2.23-2.43] was observed in 2020.

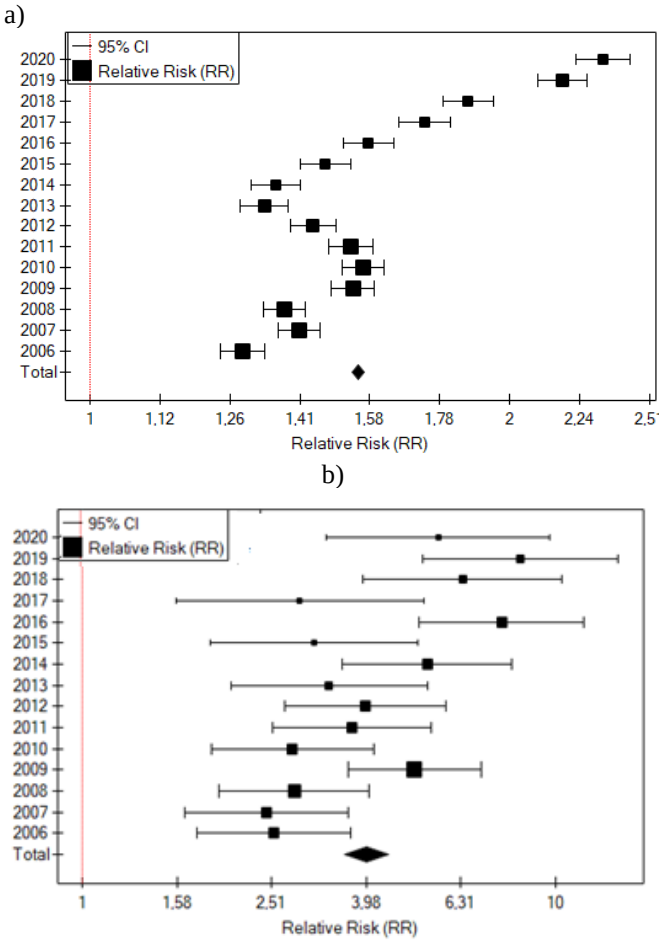

Fig. 2. RR of an accident at work in the mining industry in Poland: a) total injured, b) fatalities

The RR analysis of fatal accidents registered in the mining sector in Poland in 2006-2020 showed that the risk of this type of accident was 3.99 times higher than in other sectors. The lowest value of the relative risk was observed in 2007 (RR [95% Cl] = 2.45 [1.65-3.64]), while the highest value in 2019 (RR [95% Cl] = 8.42 [5.24 -13.53]). It was found that since 2016 (except 2017) there has been a significant increase in the RR of fatal accidents in the mining industry, which ranged from 5.64-8.41. For all the above analyses, p-value < 0.001.

Restructuring of the mining sector and reduction of coal extraction in Poland from 95.2 million tonnes in 2006 to 61.5 million tonnes in 2020, forced a reduction in employment. The largest decrease in employment (by approx. 20%) was observed between 2013 and 2016. The year 2013 was the period when the beginning of an upward trend in the relative risk of both an accident at work in general terms (RR_t) and the relative risk of a fatal accident (RR_f) was observed in mining.

The comparison of the RR_t value and the number of employees in the sector made it possible to determine the limit number of employees amounting to approx. 140 thousand, below which the risk of an accident at work, in this case fatal, clearly increases, marked in red in Fig. 3. It was found that RR_t for the number of employees above 140 thousand ranges from 1.2-1.6 (average 1.43; median 1.43), while up to 140 thousand of employees is in the range of 1.6-2.3 (average 1.94, median 1.86). The Mann-Whitney U test results show a statistically significant difference between the above groups of RR_t scores ($p < 0,001$).

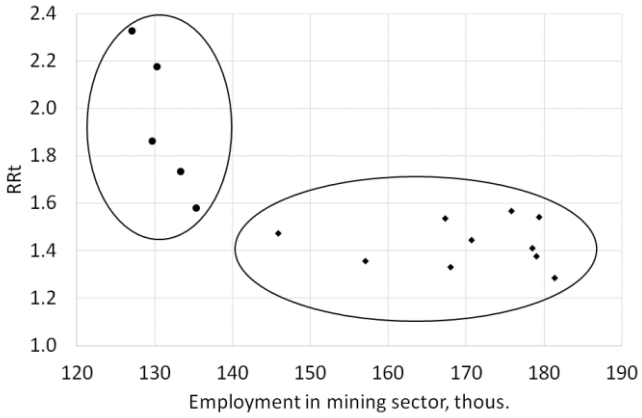

Fig. 3. The relative risk of an accident at work in the mining sector in Poland in 2006-2020

The analysis of the RR_f in the mining sector confirmed that employment in the sector below 140,000 was associated with an increase in RR_f (Fig. 4). It was found that the RR_f for the number of employees above 140,000 ranges from 2.5-5.4 (mean 3.50; median 3.21), while up to 140 thousand of employees is in the range of 2.9-8.4 (average 6.20, median 6.35). The results of the Mann-Whitney U test indicate a statistically significant difference between the above RR_f groups ($p = 0,019$).

The above results indicate an improperly balanced restructuring policy of the mining sector in Poland. Employment reduction must state a rational policy taking into account the specificity of the sector. The number of supervisory staff performing numerous inspection duties must be kept constant. These employees are responsible not only as direct supervisors of the workers, but above all their tasks include the control and maintenance of technical infrastructure (e.g., ventilation system, drainage, technical condition of workings and mining supports), on which the life of miners directly depends. Therefore, as Hao (Hao, 2012) points out, it is important to improve the construction of the supervision system through, inter alia,

strengthening the building of supervisory teams in the areas of technology and an atmosphere conducive to the supervision of works (e.g., through lack of time pressure). According to Radosavljevic (Radosavljevic, 2008), it is necessary to develop a strategy for organisational and process transformations and to raise this issue to the level of other management functions of the company. These activities should introduce the standardisation of mining safety, e.g., through personnel training and allocation of resources, including human resources (Li et al., 2015; Erkan et al., 2016). Research by He (He and Song, 2012) shows that along with the rapid reorganisation of mines, new organisational risks appeared, which requires strengthening supervision over the safety of coal mining, intensification of technological changes and increasing outlays on work safety. According to Wang (Wang et al., 2012), the level of security reaches the level set by the government when the marginal net income is equal to the increase in security investment per ton.

Fig. 4. Relative risk of a fatal accident at work in the mining sector in Poland in 2006-2020

The analysis of the RR_f in the mining sector confirmed that employment in the sector below 140,000 was associated with an increase in RR_f (Fig. 4). It was found that the RR_f for the number of employees above 140,000 ranges from 2.5-5.4 (mean 3.50; median 3.21), while up to 140 thousand of employees is in the range of 2.9-8.4 (average 6.20, median 6.35). The results of the Mann-Whitney U test indicate a statistically significant difference between the above RR_f groups ($p = 0.019$).

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As an example of bad practices, the following event can be mentioned which takes place in one of the Polish mines, where the shortages in employment of the technical department resulted in inaccurate, hasty inspections of the mining support in one of the side corridors. No mining works were carried out in this corridor, therefore the inspection and its acceptance was carried out superficially. Such a disrespectful approach to duties resulted in the fact that, two months after the inspection, a group of workers replacing the pipeline in the corridor with corroded mining housing, being convinced of its good technical condition, violated its load capacity. As a result of the collapse of the roof, three miners were buried, including one to death.

Wang points to the need to resolve the conflict between the current production and the safety of the mines and their state of development (Wang et al., 2012). In line with the actual situation of mining enterprises, the author points out that the mine's safety system depends on four factors - man, machine, environment and management. Joy points out how important it is to design mining operations in terms of risk management (Joy, 2004), putting emphasis on the importance of the reactive side of event analysis. Reactive management allows for conclusions based on the events that have occurred and the statistical analysis (Yan and He, 2010; Ural and Demirkol, 2008), including the built-up statistical models (Maiti and Khanzode, 2009; Sari et al., 2009). As Liu (Liu et al., 2021) argues, experience shows that a management system based primarily on experience, such as statistical analysis or institutions, rather than on prior checking, leads to the generation of a high number of accidents. Serious violations of safety standards related to the most important threats affecting high-risk conditions were also the subject of Kinilakodi (Kinilakodi and Grayson, 2011) studies, which propose the classification of mines using e.g., the safe performance index.

4.2. Model of risk of fatal accidents in mining

Using Kendall's r statistic, the linear relationship between RR_t and RR_f was confirmed ($p = 0.037$; $\tau = 0.402$). The RR_t and RR_f values were used to build a linear model described by the equation (3):

$$RR_f = -1.832 + RR_t \cdot 3.896 \quad (3)$$

where:
RR_f – relative risk of a fatal accident,
RR_t – relative risk of an accident at work.

The model was determined for the RR_t range between 1.28 and 2.33. Based on the model, it was found that obtaining the RR_t of an accident at work in the mining industry at the level of the national average ($RR_t = 1$) will be associated with a twice higher risk of a fatal accident in the mining sector ($RR_f = 2.06$). To obtain the risk level of a fatal accident in the mining industry, $RR_f = 1$, it is necessary to ensure safety in the sector below the national risk level ($RR_t = 0.725$). In the mining sector, which is one of the most dangerous sectors of work, achieving such a level of security is associated with taking extraordinary measures and strict application to them by all participants of the work. Only then can RR_t levels be achieved in a sector with a high level of risks lower than for the entire national economy.

Many researchers dealing with risk research in the mining sector and case studies of individual events propose a number of good technical and organisational practices aimed at managing human resources and the technical work environment. These practices most often result from developed empirical management models. According to Liu (Liu e tal., 2019), in order to improve the safety management model in underground coal mines and the transformation from passive to active management, a risk pre-control continuum and risk gradient control in underground mining are necessary. Initial risk control and management initiatives are constantly increasing, from the crisis management model to the defect management model to the risk management model.

Kent (Kent, 2015) points to two different points of view; one is risk-based (Australian) and the other is regulatory (US). The key difference is that the former transfers control, and thus responsibility, to the mine owner and workers, and the latter transfers a large amount of responsibility to the government authorities that oversee the owners of the mine to ensure that they comply with the law. Orsulak (Orsulak et al., 2010) analyses the frequency of security breaches and their consequences. The emphasis is on establishing a risk matrix based on experiences that can give an early indication of emerging potentially serious problems. The resulting frequency, consequence and risk rankings are tools for prioritising resource allocation, defining control strategies, and contributing to more proactive accident and injury prevention.

Li (Li, 2009) proposes a risk index method that is used to initially describe the degree of safety hazard in a mine in a quantitative manner and presents a macroscopic computational model. At the same time, it proposes two different methods of risk control, stating that risk precautionary and control measures are a dynamic process that underpins the implementation of dynamic safety risk management.

The use of a hierarchical model by taking into account the aspects of a coal mine disaster, personnel, equipment, environment and management is proposed by Liu (Liu and Jiang, 2012). The model, using a double standard ranking filter, provides managers with strategic information necessary to manage risk by means of a filtering and risk assessment method. At the same time, it should be taken into account that the mine safety system is an extremely complex system that usually adopts non-linear characteristics (Liu et al., 2008).

Indicating the necessity of undertaken actions, they can be graphically presented as a closed cycle, shown in Fig. 5.

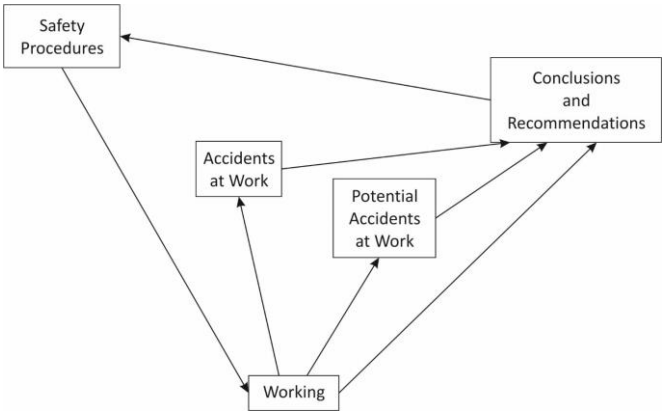

Fig. 5. A model of activities aimed at improving safe work procedures

Employers/owners of plants, including mines, should take into account all recommendations resulting from the analysis of accidents at work and near-accident events in the work procedures developed, which indicate on a safe way of doing ajob. Proactive activities allow to improve work procedures based on conclusions from the work performed and near-accident events. Reactive actions allow for changes only on the basis of accidents at work. The goal of all work organisers should be that all conclusions result from proactive activities, which should result of minimising the number of accidents at work.

5. Summary and conclusion

The energy transformation is associated with changes in priorities in the national economy. The leading sectors, such as hard coal mining, are being limited due to the declining demand for their product. These limitations are related to a reduction in production and, consequently, a gradual reduction in employment. It is important that the decrease in the number of employees does not result in a decrease in safety at work.

Restricting the mining sector in Poland in recent years has resulted in unsustainable management of the level of security. Despite the decline in the absolute number of people injured in accidents at work in the mining industry, the level of relative risk in the mining sector has been increasing since 2013. This increase may be due to a greater emphasis on coal mining

at the expense of preventive control measures. On the basis of the conducted analysis, it was found that, in Poland, the decrease in the number of employees below 140,000 caused a sharp increase in the relative risk of accidents at work in the mining sector. The analysis of fatal accidents showed that in Poland the risk of a fatal accident in the mining industry in 2020 was 5.64 times higher than in the entire national economy (the highest in 2020 $RR_f = 8.42$).

The presented results of the analysis, especially in the period of transformation, indicate the need for actions not only reactive. Proactive activities, indicated by researchers as components of many safety models in the mining sector, should cover both the technical, organisational, and human areas, bearing in mind the natural hazards. The results of reactive and proactive analyses should be included in the development and corrections of production procedures on an ongoing basis in order to prevent the release of energy from negatively affecting employees to the maximum extent possible.

Implementing preventive solutions, occupational health and safety training, analysing the state of occupational health and safety in the industry and monitoring working conditions and threats in the work environment are becoming a key element enabling the development of safe and hygienic working conditions, which is also emphasized in studies devoted to - issues of occupational safety in mining industry (Brodny et al., 2018; Chen et al., 2012; Chen et al., 2013; Ruipeng et al., 2019; Trenczek, 2015), but also non-coal mines (Wu et al., 2023) or other branches of the economy (Klimecka-Tatar et al., 2023).

The conducted research may constitute the basis for making comparisons between industries. They may also be extended to cover accidents in other countries, not just those limited to the mining industry.

Acknowledgements

The publication is supported by the Rector's pro-quality grant. Silesian University of Technology, 11010/RGJ22/0039.

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