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RISK OF INJURIES AMONG COAL MINE WORKERS AND ITS HYSTERESIS

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The paper gives an overview of employment in coal mining, levels of extraction and injuries among the coal mine operators in Poland over a span of time from 1954 through to 2010. The injury indicators, such as the incidence rate, severity and the generalized loss index, have been assessed for a period of coal mining sector restructuring from 1993 to 2010. Diverging trends have been revealed, resulting in a need to extend the time span of the analysis. Analysis of records from 1954 to 2010 has shown a multiple cyclicity of trends of change in the values used to derive coefficients. The definition of the Injury Risk has been justified, along with a new way for its representation and its interpretation as a new method with account of the previous studies. Based on this method the injuries at the coal mines of Poland during a period of their restructuring have been investigated with analyzed database expansion to include records from 1954 to 2010.As a result a new dependency, namely the injury risk hysteresis, has been identified. A proposed new method for assessing the injury risk is universal and can be applied not only to the coal mines, but to any facility of any sector within the country and even at the inter-state level. The method can be used to analyze data on the injury incidence rate per 1000 people and the injury severity rate over any span of time.

Key words: coal extraction, injury indicators, risk hysteresis, coal mines restructuring.

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Introduction. *Injuries and their indicators at coal mines in a restructuring period and the preceding years.* Most accidents with the coal mine workers are related to the coal extraction. General dynamics of injuries, fatalities, extraction and employment levels at the coal mines of Poland in a period from 1954 to 2010 is presented in Fig. 1 [4].

The analysis of total injuries reveals typical extremes in the injury, employment and extraction rates in different years. The extremes do not overlap by years, and the dynamics of curves does not demonstrate similarity. Therefore mine safety assessment based on the injury rates is not objective. Nevertheless the dynamics of total injuries shows typical extremes (maximums) in 1991 and earlier, in 1981, 1969 and 1957 and minimums in 2005 and earlier, in 1988, 1977, 1966 and 1955.

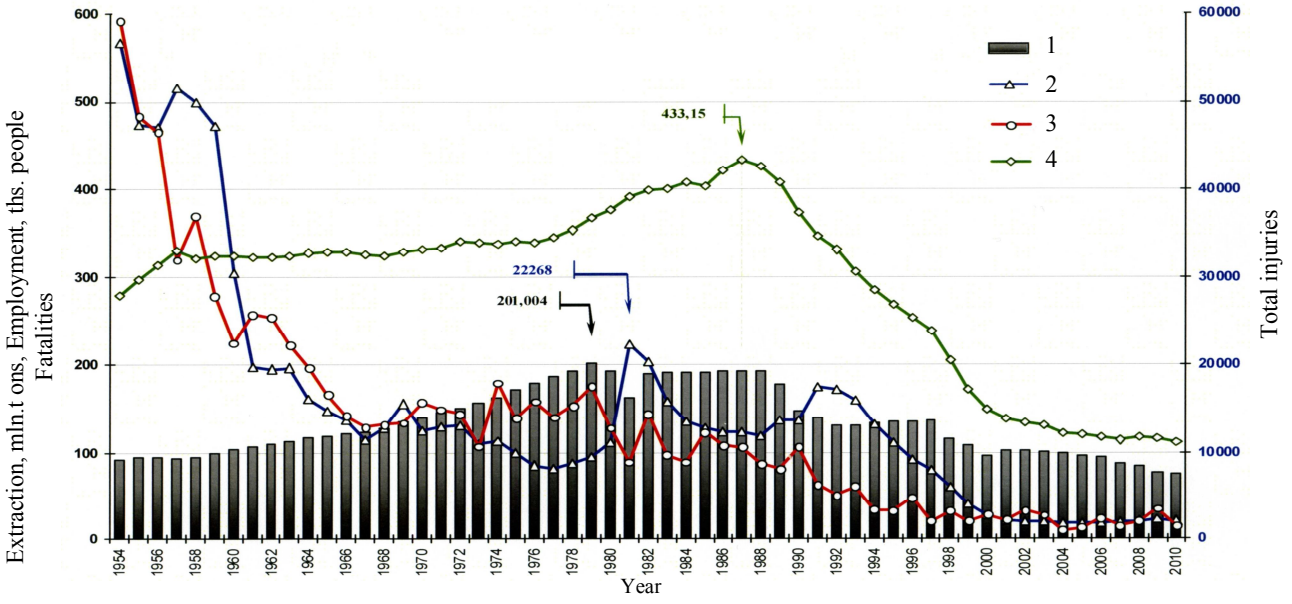


Fig. 1. Extraction, injuries and employment at coal mines in 1954-2010
1 – extraction, mln. tons; 2 – total Injuries; 3 – fatalities; 4 – employment, ths. people

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As the graphs in Fig. 1 show, the local extremes (maximums) of total injuries are not associated with abrupt changes in the number of fatalities resulting from the catastrophes. Nor are they are associated with the increase in employment and extraction rates. Local maximums of injuries are seen in 1981 with the employment growth, while in 1991 with its decrease.

Neither employment rates nor changes in levels of extraction impacted the extremes (minimums and maximums). With respect to the level of extraction in 2005 the number of injuries decreased, in 1988 it was flat, and in 1977 and 1967 increased. Employment until 1967 (331 ths. workers), the sames as in 1977 (334 ths. workers) was flat, and hit its maximum in 1988 (above 400 ths. workers), while the downward trend was observed in 2005 (121 ths. workers).

Characteristic is also the fact that in 1988 the total number of injuries (11904 cases) was higher than in 1977 (8127 cases) with the same level of extraction (183 vs 186 mln. tons), but with higher employment (425 vs 344 ths. workers).

The figures above imply that the progress in technology does not always mean reduction in the number of injuries, and the achieved reduction in the injury rate can be unstable. It is also possible, that the downward trend in the rate of injury observed in 2000s in the near future may again go up, and the future minimums and maximums may exceed the rates of the previous periods.

The facility safety level up to now has been assessed based on the injury coefficients. These are the injury incidence coefficients W_Z, W_T and W_G, the injury severity coefficient C and the generalized loss index W_{US}. The choice of indicators used to assess the injury level is as a rule optional, as there are no rules saying when and which indicator shall be used. Coefficients W_Z and C are published in official statistic reports. W_Z coefficient is used more frequently than other indicators to analyze the injuries, as it can be applied to almost any business area. Trends in its value are rarely associated with C coefficient.

The generalized loss index [8], defined in the Polish literature, as an injury preventive coefficient, is quite rarely used to analyze the injuries. It is rather specific, as includes occupational risk elements - the injuries frequency and severity. In practice the injuries are usually analyzed for a certain time span, which is as a rule five years, and depending on the coefficients the results are represented in the graphs either combined together or separated.

The full dynamics of injury rates in a period of coal mines restructuring in Poland from 1993 to 2010 is shown in Fig. 2 [4]. This period is extremely important for the coal mining sector due to

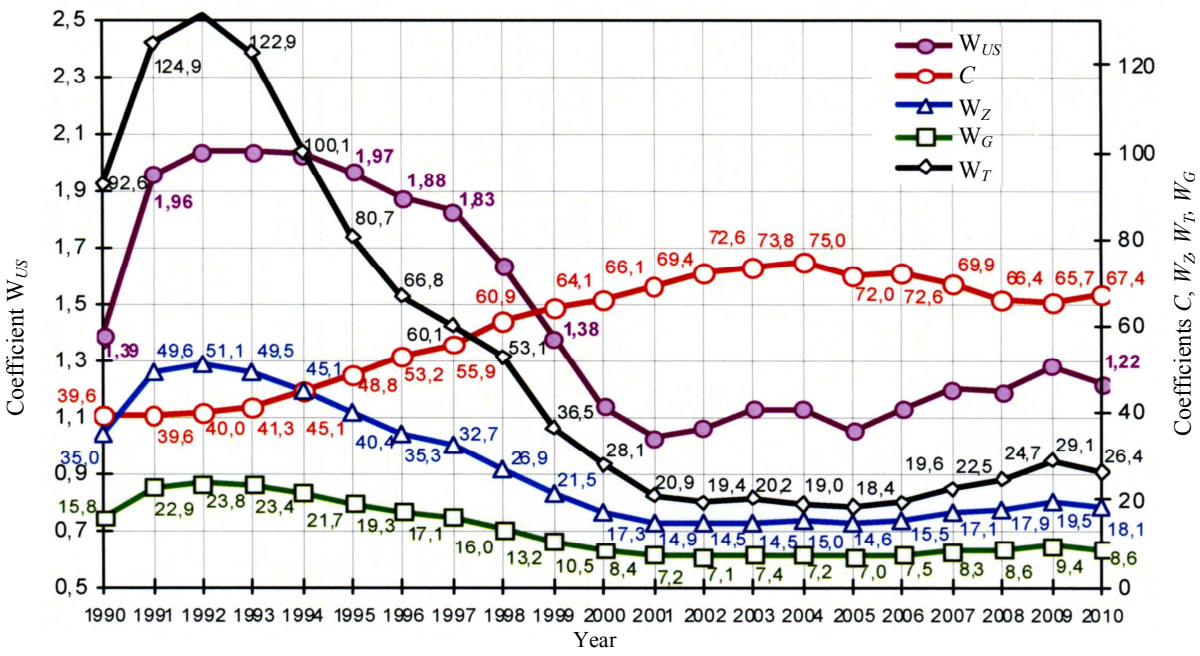


Fig. 2. Injury coefficients for restructuring period [4]

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changes it brought about, as it was when the sector transited from the administrative distribution system to the market relations, which became the focus of research in publications on the economics, sociology, occupational safety, etc.

In order to explore the injury rates the following coefficients were used:

$$C = \frac{D_S}{W - W_{sm}};\ W_Z = \frac{W}{Z}\cdot 10^3;\ W_G = \frac{W}{D}\cdot 10^5;\ W_T = \frac{W}{T}\cdot 10^3;\ W_{US} = W_Z 10^{-3} C,$$

where C is the injury severity rate; W is the total number of accidents, W_Z - per 1000 workers, W_G - per 100 000 man shifts, W_T per 1 mln. tons; W_{US} is the generalized loss index; W_{SM} is the number of fatalities; Z is the number of employees at the facility; D is the number of worked man shifts; T is the volume of clean (marketable) coal; D_S is the number of shifts lost due to injuries.

When evaluating the safety level for this period a positive downward trend in the injury incidence rate is seen from 1992 to 2003 and negative growth of injury severity rate is observed.

The multistage studies carried out by the author [1-6, 7] to assess safety level in the coal mines during the period of restructuring involved comparison between coefficients W_Z, C, W_{US} across the coal mines over a period from 1954 to 2010 (Fig. 3). Within this broad time span certain specific dependencies between the injury incidence and severity rates have been identified, which previously were not found and described in special literature. With increase in injury incidence (W_Z coefficient) the severity (C coefficient) decreases, while with decrease in the incidence rate the severity rate increases. Certain periods have been identified in retrospective – 2004-1991, 1991-1981, 1991-1977, etc. There is also similarity between the curves of W_Z and W_{US} coefficients.

Research methods and techniques. *Injury risk notion.* For more unambiguous assessment of the occupational safety level based on the method of coefficients it is proposed to introduce the Injury Risk notion into the practice [1-3, 6]. This term is used in professional literature, but is not recognized as an official term and legal concept in the regulatory and legal documents (laws, regulations, decrees, standards, etc.). This term is most frequently used to describe or evaluate the incidence of injuries, the safety status, preventive activities, etc. This notion is as a rule expressed as a comparison (high, low, improvement, deterioration) or through the values of overall incidence, number of severe (fatal) injuries or in any other generally recognized way. The injury rate is often correlated with the notion of occupational risk.

According to the Polish standards the probability of the accident and its consequences shall be assessed and determined based on a three- or five-point scale. There is no unified method to assess the accident probability and losses. The data source is often statistics, where losses are correlated with the reported injuries by their consequences (severe, fatal), and the accident probability is correlated with W_Z indicator. Thus, it is justified to accept the following definition for the practical use: "*The Injury Risk shall mean the incidence of negative events associated with the job functions, leading to the loss of labour capacity or the health of the worker, and as a consequence to the inability to perform job functions due to the hazard*".

The definition can be described by the following expression:

$$R_W = W_Z C = \frac{W}{Z}\cdot 10^3 \frac{D_S}{W\text{-}W_{sm}} \approx \frac{D_S}{Z}\cdot 10^3.$$

Mathematical analogue of the general injury indicator W_{US} is the injury risk coefficient R_W. No additional actions or calculations to derive the coefficient components from the injury statistics are required, as they are published in a standard form.

Results and discussion. *Analysis and injury risk assessment methods.* The rough method presently used to represent data for assessing the injury rate (the injury risk) in the coal mine is

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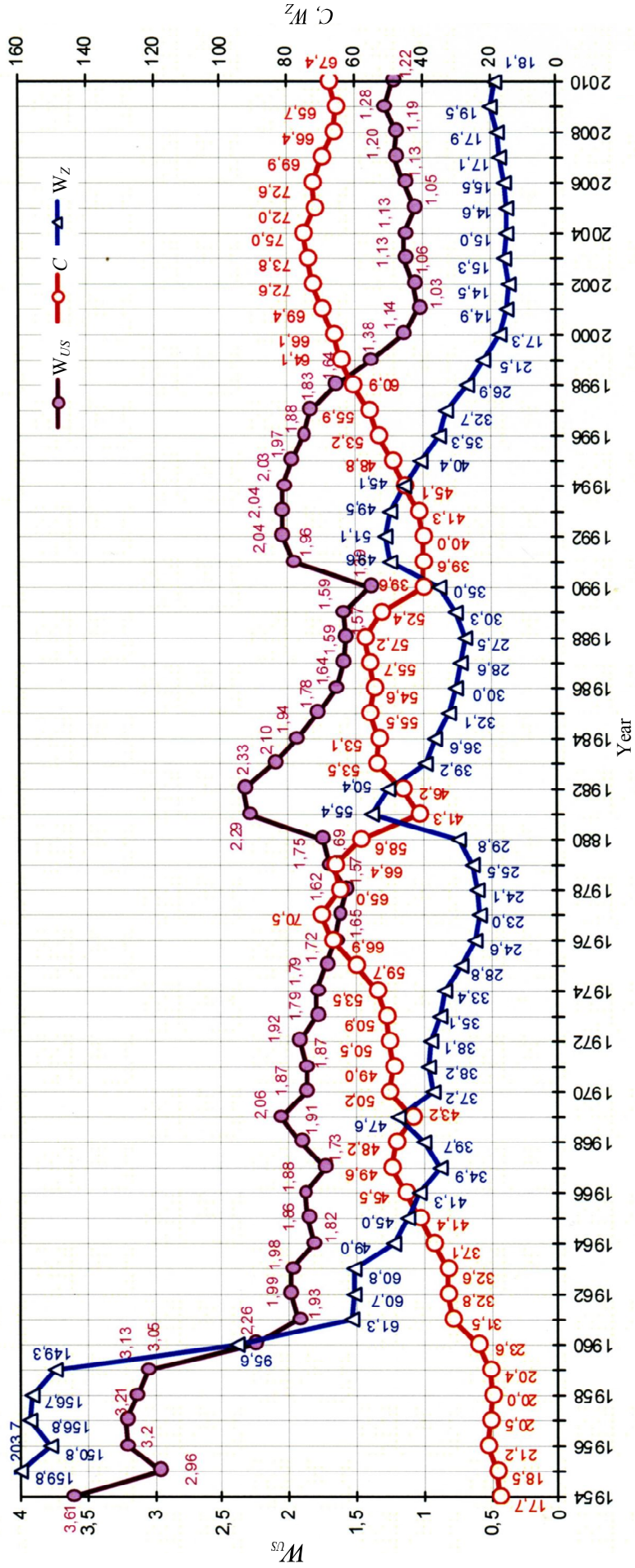


Fig. 3. Trend of change in the injury coefficients W_Z, C and W_{US} at coal mines from 1954 to 2010 [4]

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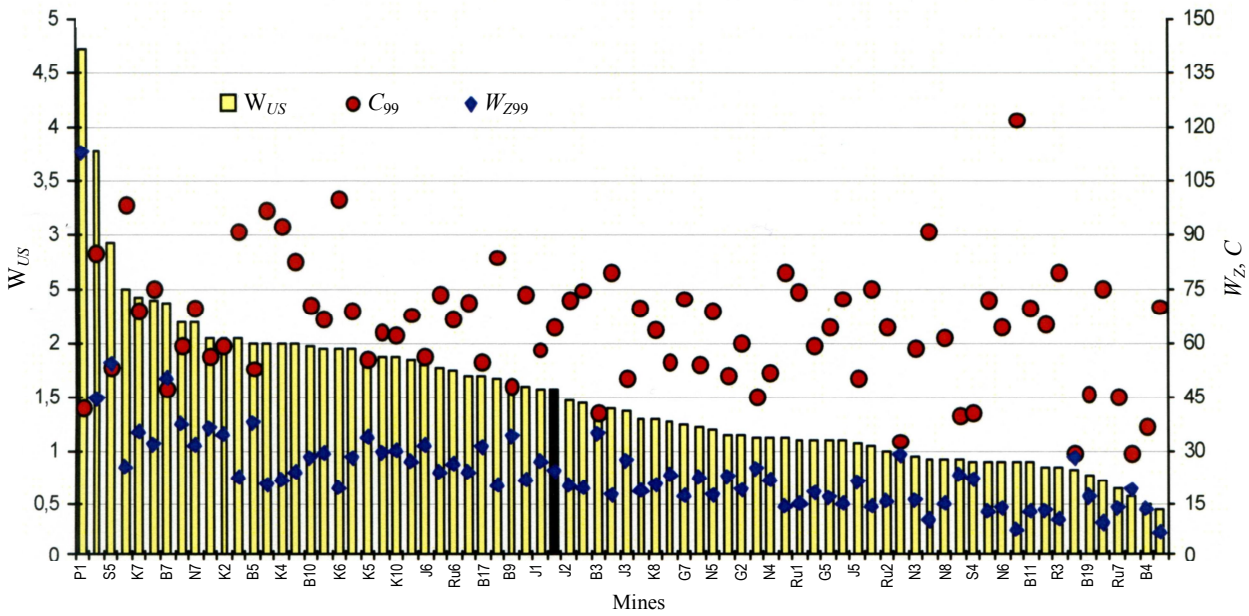


Fig. 4. Distribution of values of the generalized loss index (in descending order) and its components W_Z and C for the coal mine in 1999

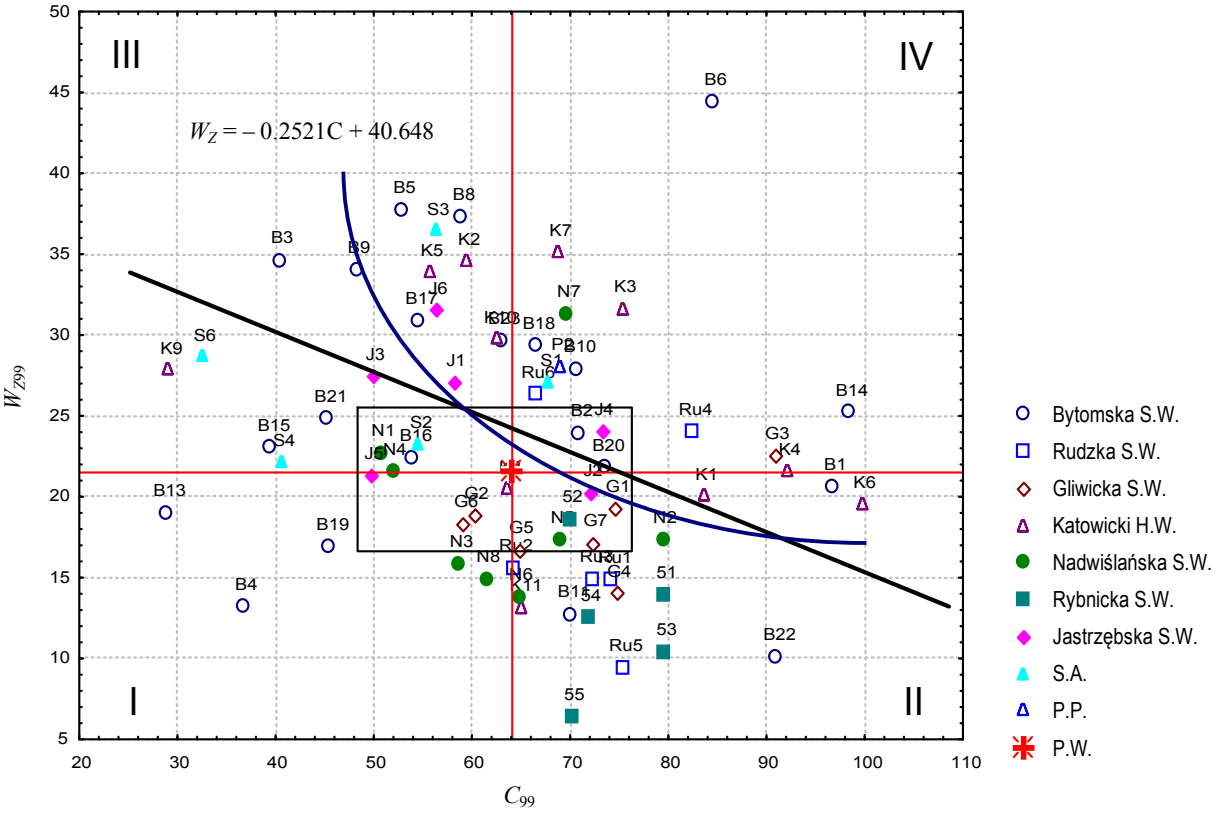


Fig.5. Injury risk at coal mines of various production associations in 1999 [2, 3, 8]

shown in Fig. 4, where one graph presents the values of W_{US} coefficient, systemized by reduction, and respectively the values of its components W_Z and C. Interpretation of W_{US} coefficient by its components W_Z and C is complex and ambiguous, which may lead to controversial conclusions and impossibility to make comparison between different periods. This in its turn leads to rare use of the coefficient for formal assessment of injuries, which cannot find a broader application.

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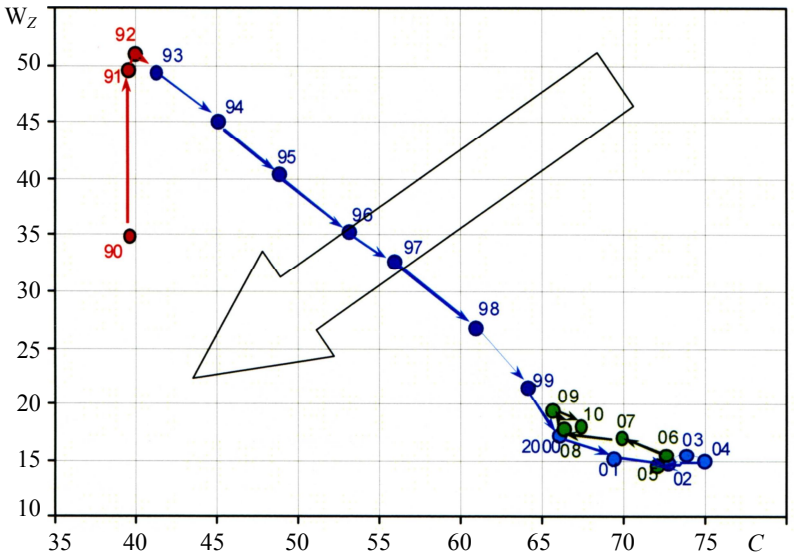


Fig. 6. Trend of change in the injury risk value R_W (*WZ, C*) at coal mines from 1990 to 2010 [3, 4]

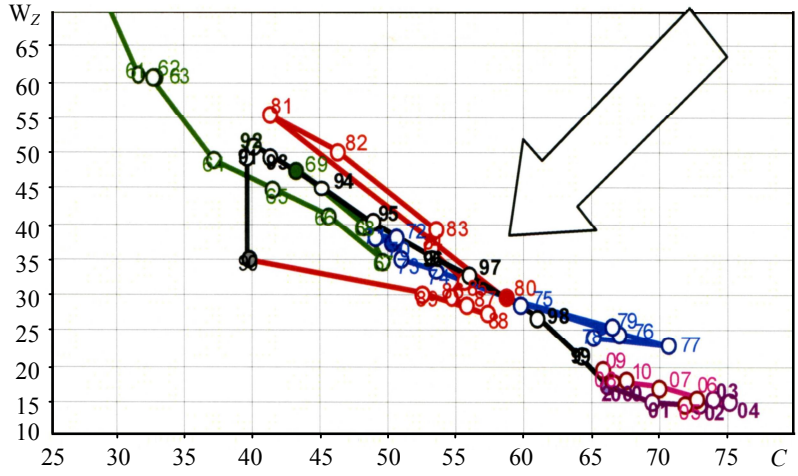


Fig. 7. Trend of change in the injury risk value R_W (*WZ, C*) at coal mines from 1960 to 2010

Injury risk R_W and values of its components W_Z and C can be represented in another way different from the shown above. By inserting the corresponding values of WZ and C components for certain mines into the rectangular system of coordinates we obtain the points illustrating the injury risk in these mines [3, 7] (Fig. 5). Thus one point in Fig. 5 reflects three parameters – the injury risk, incidence and severity rate for the given facility, i.e. the coal mine, which appears to be more illustrative and unambiguous than what is shown in Fig. 4.

Mean values of the injury risk can be obtained with the help of:

- the arithmetic mean R_W, when the components (mean values of W_Z and C coefficients) divide the coordinates plane into four quadrants (I-IV) of the injury risk value;
- the straight trend line (mean value), dividing the plane into the higher and the lower values of the injury risk;
- the hyperbolic curve, dividing the plane into the higher and the lower values of the injury risk.

The tendencies and trends of injury risk over a certain span of time (restructuring period) can be represented in the rectangular coordinate system as a curve of functions of its components $R_W(W_Z,C)$ (Fig. 6). In Fig. 6 the arrows connect the points corresponding to the risk values for each year, forming an injury risk curve. The arrow in the graph shows the hypothetical positive trend of the injury risk reduction based on the assumption, that each recorded injury is a random variable and therefore the severity of injury (days of traumatic rehabilitation) also becomes a random variable.

It is assumed that the random decrease in the frequency and the number of injuries reduces the number of injuries with short or long post-traumatic rehabilitation and their severity will also be reducing. This thesis was accepted in the studies conducted by the author in 2000 [6, 7], but was not confirmed, as the trend of injury risk shifting towards decrease in the incidence rate W_Z– and increase in the severity C+ of recorded injuries was identified. After 2000 the injury risk trend was changing in a looplike manner, demonstrating a new quality of relationship (Fig. 6). Upon extension of the research time span back to 1990 and then back to 1954 unexpected results were obtained.

The curves built based on the injury coefficient values for a period from 1954 to 2010 have demonstrated the multiple cyclicity. The injury risk curve for a period from 1960 (Fig. 7) confirms

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the trend of multiple cyclicity in the form of multiple loops on R_W curve. In natural sciences such type of dependency of the system's actual state on its state in the previous periods is called the hysteresis. Without hysteresis loop the graph represents only one part of the curve and can even be treated as the linear dependency.

The injury risk has never been previously described and illustrated in details as function f(C, WZ) in special literature in Poland or any other country. Neither has the looping on the injury risk curves of a hysteresis nature been identified or described. It is the first time when the detailed graphic representation of injury risk dynamics is provided. The aforesaid dependency was identified based on the official statistics of recorded injuries among the coal mine workers.

Trend of change in the injury risk curve with account of looping gains similarity to the hyperbolic function. The curve demonstrates an evident trend of approaching to and moving away from zero value, which in the studies carried out by the author was recognized as a positive trend of injury risk reduction. Both right-hand and left-hand looping has been recorded.

Injury risk hysteresis is observed not only in a period of coal mining restructuring, but also in the earlier periods. This dependency is typical for both the planned and the free market economy. Its manifestation in future is not excluded, which provides a possibility to forecast it.

Conclusions

1. Parameters used to asses the overall picture of injuries, such as extraction, employment and injury incidence both in the period of coal mines restructuring in Poland in 1993-2010 and in earlier periods, starting from 1954, demonstrate considerable volatility, but make it possible to single out the same values in different years and distinguish typical cycles. For example, extraction and employment levels in 1989 and 1976 were almost the same, while the injury rate in 1976 was much lower than in 1989, despite the progress in technology.

2. The injury incidence rate per 1000 workers and the injury severity rate show the inverse relationship, i.e. when the incidence rate increases, the severity decreases and vice versa. The typical periods or cycles of such changes can also be identified.

3. The method previously used to assess the injury rate based on the method of coefficients is demonstrating a rather discretionary nature of the used coefficients, analysis time spans, result representation techniques, due to which conclusion made based on the findings can be ambiguous and misleading.

4. A new method for assessing the injury risk R_W does not imply introduction of any new coefficients, requiring only the unambiguous use of injury incidence rate W_Z and severity rate C in order to carry out the analysis and accurately interpret its results.

5. Assessment of the injury risk as used for the coal mines can also find application in other industries, and inter alia can be used for comparing coal mining sectors on a global scale.

6. A new method for assessing injury risk helped to identify a new dependency, which has not been yet described in the special literature, called the injury risk hysteresis.

7. Injury risk analysis covering the period of coal mines restructuring in Poland from 1993 to 2010 has shown that this period is too short to obtain reliable results, and the analysis for each subsequent year shall be carried out with account of the hysteresis line starting from 1960.

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