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# Estimating possible rate of injuries in coal mines

*The article presents methods to calculate the values of injury rates in mines. The authors demonstrated how to estimate the value of compensation paid to the injured employees in the successive years (particularly next year). The research was performed based on the data from several hard coal mines.*

*key words: safety, occupational health and safety, accident rate, injuries rate, predicting volume of compensation payments in the mining industry.*

## 1. INTRODUCTION

One of the major ways to estimate risk in industrial companies with increased degrees of hazards, particularly in coal mines, is to check the rate of the employees' injuries. The article features an analysis of the rates of injuries and work-related diseases among the employees of the coal industry. In the article the authors used the data obtained from the social and accident insurance company of the Gorniatska district in the town of Makeevka, Makeevugol mine, Lenin mine, Kholodnaya Balka mine, Glubokaya mine, and a private manufacturing company Gorniak-95.

The Gorniatska district is located in the southern part of Makeevka and is the most populated district of the town (population 99,800).

In the paper the authors will determine the initial dynamics of injuries and work-related diseases in Gorniatska's coal mines. For this reason, some data will be excluded from the obtained data, i.e. the statistics of work-related diseases and injuries, along with their dynamics, which are not related to the operations of the mining industry. Additionally, the analysis will not cover the impact of demographic and epidemic factors which increase the rate of injuries in the district. This way, excluding the injuries and diseases not related to the mining industry operations, it is possible to correct the dynamics of the injuries and work-related diseases in mining companies of the Gorniatska district.

Table 1 features the results for the period 2001-2011, with the consideration of the injuries rate for four mines.

**Table 1.**

**Injuries rate 2001-2011**

| **Injuries rate in coal mines** | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | **2001** | **2002** | **2003** | **2004** | **2005** | **2006** | **2007** | **2008** | **2009** | **2010** | **2011** |
| Lenin mine | 61 | 64 | 83 | 81 | 47 | 36 | 43 | 42 | 43 | 45 | 70 |
| Kholodnaya Balka mine | 70 | 87 | 88 | 78 | 58 | 49 | 49 | 47 | 64 | 67 | 60 |
| Gorniak-95 | 7 | 4 | 23 | 13 | 10 | 18 | 10 | 15 | 14 | 17 | 26 |
| Glubokaya mine | 224 | 219 | 162 | 107 | 75 | 46 | 7 | 0 | 0 | 0 | 0 |

Based on the collected data, a chart was prepared to demonstrate the changes in the injuries rate in the given period (Fig. 1). The analytical form of the basic injuries rate is usually expressed by an exponential function [1, 4] (1).

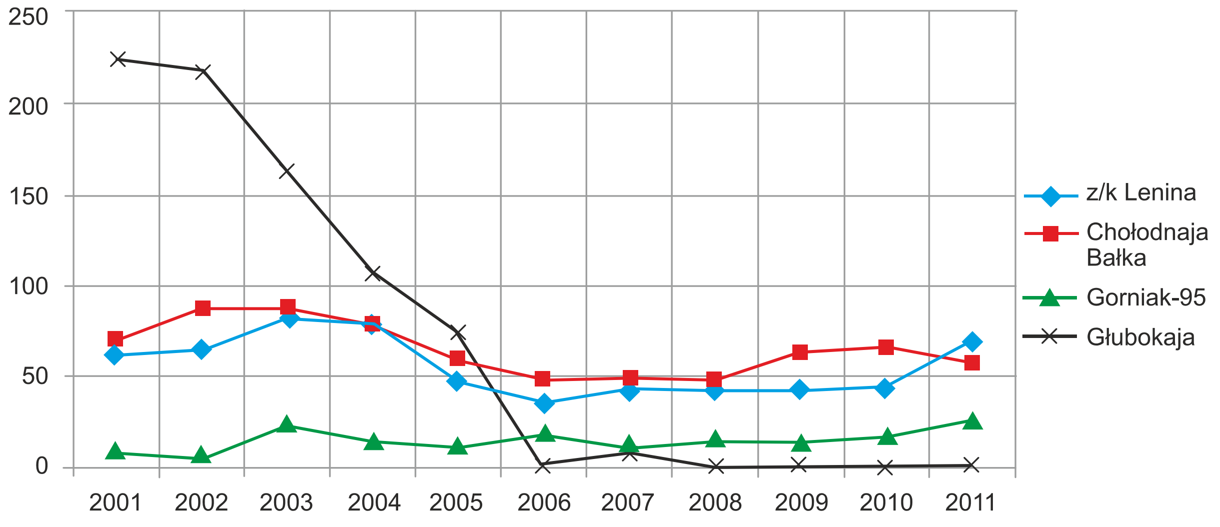



*Fig. 1. Changes in the injuries rate 2001-2011*

$$x(t) = ae^{bt} \quad (1)$$

In the formula (1) $x(t)$ stands for the basic value injury rate in the moment $t$, starting from the first year of the previous decade; $a$, $b$ are constant coefficients; $t$ – time which passed from the first year of the previous decade.

The coefficients $a$ and $b$ were determined according to the following dependencies:

$$b = \frac{n\sum_{i=1}^{n} t_i \lg x_i - \sum_{i=1}^{n} t_i \sum_{i=1}^{n} \lg x_i}{\lg e\left[n\sum_{i=1}^{n} t_i^2 - \left(\sum_{i=1}^{n} t_i\right)^2\right]}, \quad (2)$$

$$\lg a = \frac{\sum_{i=1}^{n} t_i^2 \sum_{i=1}^{n} \lg x_i - \sum_{i=1}^{n} t_i \sum_{i=1}^{n} \lg x_i}{n\sum_{i=1}^{n} t_i^2 - \left(\sum_{i=1}^{n} t_i\right)^2}, \quad (3)$$

where
$x_i$ – the value of the injuries rate in the year $i$;
$t_i$ – time which passed from the first year of the previous decade to the year $i$;
$n$ – number of observations.

The error of the predicted values of the injuries rate is calculated according to the following dependency [3]:

$$m = \pm\frac{\sigma}{\sqrt{n-1}}\sqrt{1 - \frac{n(t_j - k)^2}{\sum(t_i - k)^2}}, \quad (4)$$

where
σ – standard deviation;
$t_i$, $t_j$ – time which passed from the first year of the previous decade respectively to the year $i$ of the current decade and to the predicted year $j$;

$$k = \frac{1}{n}\sum_{i=1}^{n} t_i . \quad (5)$$

The value of the standard deviation is determined according to the following dependency [4,5]:

$$\sigma = \sqrt{\frac{1}{n-1}\left[\sum z_i^2 - \frac{1}{n}\left(\sum z_i\right)^2\right]} \quad (6)$$

The predicted values of the injuries rate are calculated according to the following dependency:

$$x_T = ae^{bT} \pm m, \quad (7)$$

where
$T$ – time which passed from the first year of the previous decade to the predicted year.

If the real values of the injuries rate in the year for which the prognosis was made are lower or equal to the values calculated according to the formula (4), it means that the number of injuries remained on the same level or decreased. If the real values are higher than the calculation values, that will indicate a real increase in the number of injuries.

The data from 2001-2010 (Table 2) were used to calculate the coefficients $a$ and $b$.

**Table 2.**

**Numerical data used to calculate the values *a, b* (Lenin mine)**

| Data for calculations | | | | | | |
|---|---|---|---|---|---|---|
| **Year** | ***N*** | $t_i$ | $t_i^2$ | $x_i$ | $lgx_i$ | $t_i\, lgx_i$ |
| 2001 | 1 | 1 | 1 | 61 | 1.785 | 1.785 |
| 2002 | 2 | 2 | 4 | 64 | 1.806 | 3.612 |
| 2003 | 3 | 3 | 9 | 83 | 1.919 | 5.757 |
| 2004 | 4 | 4 | 16 | 81 | 1.908 | 7.634 |
| 2005 | 5 | 5 | 25 | 47 | 1.672 | 8.360 |
| 2006 | 6 | 6 | 36 | 36 | 1.556 | 9.338 |
| 2007 | 7 | 7 | 49 | 43 | 1.633 | 11.434 |
| 2008 | 8 | 8 | 64 | 42 | 1.623 | 12.986 |
| 2009 | 9 | 9 | 81 | 43 | 1.633 | 14.701 |
| 2010 | 10 | 10 | 100 | 45 | 1.653 | 16.532 |
| Total | 10 | 55 | 385 | | 17.191 | 92.141 |

$$b = \frac{10 \cdot 92{,}141 - 55 \cdot 17{,}191}{0{,}4343\left[10 \cdot 385 - 55^2\right]} = -0{,}0672$$

$$\lg a = \frac{385 \cdot 17{,}191 - 55 \cdot 92{,}141}{10 \cdot 385 - (55)^2} = 1{,}8797$$

$$a = 76\,,$$

For the coefficient values calculated in this manner, the dependency (1) takes the following form:

$$x(t) = 76e^{-0{,}0672(t-2001)}\,.$$

Thus the predicted value of the total number of people with injuries in 2011 will be equal to:

$$x(11) = 76 \cdot e^{-0{,}0672*10} = 39\,,$$

$$k = \frac{1}{10} \cdot 55 = 5{,}5\,;$$

$$\sum(t_i - k)^2 = (1-5{,}5)^2 + (2-5{,}5)^2 + (3-5{,}5)^2 + (4-5{,}5)^2 + (5-5{,}5)^2 + (6-5{,}5)^2 + (7-5{,}5)^2 + (8-5{,}5)^2 + (9-5{,}5)^2 + (10-5{,}5)^2 = 85$$

$$m_n = \pm\frac{17{,}24}{\sqrt{10-1}} \cdot \sqrt{1 + \frac{10 \cdot (10-5{,}5)^2}{85}} = 11{,}0\,,$$

so

$$x_T = 39 \pm 10{,}0\,.$$

Thus it is possible to draw a conclusion that, due to the real value of the total number of injuries in the mine being 70 in 2011 (i.e. twice as high as the computational one), the performed calculations give evidence of increasing number of injuries in the Lenin mine in 2011.

Similar calculations were performed for the Kholodnaya Balka mine.

**Table 3.**

**Numerical data used to calculate the values *a, b* (Kholodnaya Balka mine)**

| Data for calculations | | | | | | |
|---|---|---|---|---|---|---|
| **Year** | **N** | $t_i$ | $t_i^2$ | $x_i$ | $lgx_i$ | $t_i lgx_i$ |
| 2001 | 1 | 1 | 1 | 70 | 1.845 | 1.845 |
| 2002 | 2 | 2 | 4 | 87 | 1.940 | 3.879 |
| 2003 | 3 | 3 | 9 | 88 | 1.944 | 5.833 |
| 2004 | 4 | 4 | 16 | 78 | 1.892 | 7.568 |
| 2005 | 5 | 5 | 25 | 58 | 1.763 | 8.817 |
| 2006 | 6 | 6 | 36 | 49 | 1.690 | 10.141 |
| 2007 | 7 | 7 | 49 | 49 | 1.690 | 11.831 |
| 2008 | 8 | 8 | 64 | 47 | 1.672 | 13.377 |
| 2009 | 9 | 9 | 81 | 64 | 1.806 | 16.256 |
| 2010 | 10 | 10 | 100 | 67 | 1.826 | 18.261 |
| Total | 10 | 55 | 385 | | 18.069 | 97.809 |

$$b = \frac{10 \cdot 97{,}809 - 55 \cdot 18{,}069}{0{,}4343\left[10 \cdot 385 - 55^2\right]} = -0{,}0439$$

$$\lg a = \frac{385 \cdot 18{,}069 - 55 \cdot 97{,}809}{10 \cdot 385 - (55)^2} = 1{,}9118$$

$$a = 82\,,$$

thus the dependency (1) has the following form:

$$x(t) = 82e^{-0{,}0439(t-2001)}.$$

The predicted value of the total number of people with injuries in 2011 will be equal to:

$$x(11) = 82 \cdot e^{-0{,}0439*10} = 53$$

The predicted value of the injuries rate is:

$$k = \frac{1}{10} \cdot 55 = 5{,}5$$

$$\sum (t_i - k)^2 = (1-5{,}5)^2 + (2-5{,}5)^2 + (3-5{,}5)^2 + (4-5{,}5)^2 + (5-5{,}5)^2 + \\ + (6-5{,}5)^2 + (7-5{,}5)^2 + (8-5{,}5)^2 + (9-5{,}5)^2 + (10-5{,}5)^2 = 85$$

$$m_n = \pm \frac{20{,}78}{\sqrt{10-1}} \cdot \sqrt{1 + \frac{10 \cdot (10-5{,}5)^2}{85}} = 13{,}0\,,$$

$$x_T = 53 \pm 13{,}0\,.$$

The real value of the total number of injuries in the mine was 60 in 2011. Due to the fact that the predicted value of the injuries rate changes from 40 to 66, it can be stated that the injuries in the Kholodnaya Balka mine remained at the same level in 2011.

The data and calculations presented below (Table 4) refer to the Gorniak-95 company.

**Table 4.**

**Numerical data used to calculate the values *a*, *b* (Gorniak-95)**

| Data for calculations | | | | | | |
|---|---|---|---|---|---|---|
| **Year** | **N** | **$t_i$** | **$t_i^2$** | **$x_i$** | **$\lg x_i$** | **$t_i \lg x_i$** |
| 2001 | 1 | 1 | 1 | 7 | 0.845 | 0.845 |
| 2002 | 2 | 2 | 4 | 4 | 0.602 | 1.204 |
| 2003 | 3 | 3 | 9 | 23 | 1.362 | 4.085 |
| 2004 | 4 | 4 | 16 | 13 | 1.114 | 4.456 |
| 2005 | 5 | 5 | 25 | 10 | 1.000 | 5.000 |
| 2006 | 6 | 6 | 36 | 18 | 1.255 | 7.532 |
| 2007 | 7 | 7 | 49 | 10 | 1.000 | 7.000 |
| 2008 | 8 | 8 | 64 | 15 | 1.176 | 9.409 |
| 2009 | 9 | 9 | 81 | 14 | 1.146 | 10.315 |
| 2010 | 10 | 10 | 100 | 17 | 1.230 | 12.304 |
| Total | 10 | 55 | 385 | | 10.731 | 62.150 |

$$b = \frac{10 \cdot 62{,}150 - 55 \cdot 10{,}731}{0{,}4343\left[10 \cdot 385 - 55^2\right]} = 0{,}0874$$

$$\lg a = \frac{385 \cdot 10{,}731 - 55 \cdot 62{,}150}{10 \cdot 385 - (55)^2} = 0{,}8643$$

$$a = 7\,,$$

In this case the dependency (1) takes the following form

$$x(t) = 7e^{0{,}0874(t-2001)}.$$

The predicted value of the rate of total number of people with injuries in 2011 will be equal to:

$$x(11) = 7 \cdot e^{0{,}0874*10} = 17$$

$$k = \frac{1}{10} \cdot 55 = 5{,}5$$

$$\sum (t_i - k)^2 = (1-5{,}5)^2 + (2-5{,}5)^2 + (3-5{,}5)^2 + (4-5{,}5)^2 + (5-5{,}5)^2 + \\ + (6-5{,}5)^2 + (7-5{,}5)^2 + (8-5{,}5)^2 + (9-5{,}5)^2 + (10-5{,}5)^2 = 85$$

$$m_n = \pm \frac{4{,}14}{\sqrt{10-1}} \cdot \sqrt{1 + \frac{10 \cdot (10-5{,}5)^2}{85}} = 3{,}0\,,$$

$$x_T = 17 \pm 3{,}0\,.$$

When analyzing the obtained results it can be seen that the real value of the rate of total injuries number in 2011 was 26. As the predicted value of the injuries rate changes from 14 to 20, it can be stated that the injuries rate for 2011 increased in Gorniak-95.

**Table 5.**

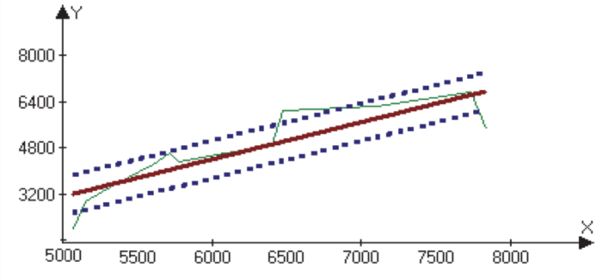
**Regression analysis – impact of particular factors on the number of injuries and the amounts of paid compensation**

| No | Dependency | $y = ax_1 + b_1; \overline{y} = ax_1 + b_2; \underline{y} = ax_1 + b_3;$<br>$y = a_1x_1 + a_2x_2 + b$ | Correlation coefficient, *r* | $X_1$ min | $X_1$ max | $X_2$ min | $X_2$ max | Confidence interval for: $a_1$ | $a_2$ | *b* | *r* |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| 1 | Coal output depending on the number of employees and injuries (Fig. 2.a) | $y = 1{,}29x_1 - 3346{,}05$<br>$\overline{y} = 1{,}29x_1 - 2694{,}61$<br>$\underline{y} = 1{,}29x_1 - 3997{,}49$<br>$y = 1{,}4x_1 - 28{,}42x_2 - 2989{,}75$ | 0,87 | 5071 | 7832 | 13 | 79 | 0,73; 1,84<br>1,05; 1,75 | -44,7; -12,14 | -6821,17; 129,07<br>-5159,33; -820,18 | 0,7; 1 |
| 2 | Compensation payments to the injured depending on the number of people with injuries | | | | | | | | | | |
| | Kholodnaya Balka (Fig. 2.b) | $y = -85{,}12x + 12240.78$<br>$\underline{y} = -85.12x + 12240.78 - 8988.14\sqrt{0.00065*(x-62.5)^2 + 0.125}$<br>$\overline{y} = -85.12x + 12240.78 + 8988.14\sqrt{0.00065*(x-62.5)^2 + 0.125}$ | 0,47 | 47 | 88 | | | -243,02; 72,79 | | 2131,78 22349,78 | -1; 0,45 |
| | Gorniak-95 (Fig. 2.c) | $y = -85.12x + 12240.78$<br>$\underline{y} = -14.57x + 752.44 - 1301.61\sqrt{0.00065*(x-15)^2 + 0.125}$<br>$\overline{y} = -14.57x + 752.44 + 1301.61\sqrt{0.00065*(x-15)^2 + 0.125}$ | 0,16 | 10 | 23 | | | -102,02; 72,88 | | -606,54; 2111,41 | -1; 1 |
| | Lenin (Fig. 2.d) | $y = -63.82x + 7490.64$<br>$\underline{y} = -63.82x + 7490.64 - 5863.92\sqrt{0.00065*(x-52.38)^2 + 0.125}$<br>$\overline{y} = -63.82x + 752.44 + 5863.92\sqrt{0.00065*(x-52.38)^2 + 0.125}$ | 0,68 | 35 | 83 | | | -131,75; 4,11 | | 3741,27; 11240,04 | -1; 0,2 |
| | Compensation payments to the injured depending on the number of people with injuries (linked data) (Fig. 2.e and Fig. 2.f) | $y = -67.78x + 933.49$;<br>$\underline{y} = 67.78x - 508.23$,<br>$\overline{y} = 67.78x + 2375.2$<br>$y = -3.49x^2 + 390x - 4420.27$ | 0,52<br>0,81 | | | | | 19,1; 116,46<br>249; 531 | -4,97; -2 | -1482,02; 3349<br>-7255; -7585 | 0,22; 0,83 |
| 4 | 2 | | | | | | | | | | |
| | Amount of compensation paid to one injured person in the successive years | $y = 19.77x - 39554.19$ | 0,87 | | | | | 8.54; 31 | | -62085.5; -1722.89 | 110.96; 295.6 |
| | a) Kholodnaya Balka | $y = 9.82x - 19670.94$ | 0,88 | | | | | 4.4; 15.24 | | -30546.9; -8794 | 29.63; 1 24.53 |
| | b) Gorniak-95 | $y = 19.13x - 38295.3$ | 0,97 | | | | | 14.58; 23.67 | | -47410; -29180.56 | 137.32; 212.94 |
| | c) Lenin | $y = 18.19x - 36409.23$ | 0,94 | | | | | 11.4; 25 | | -50057.19; -22761.27 | 107.55; 234.17 |

Coal output ($y$) depending on the number of employees ($x_1$) and the rate of injuries ($x_2$)

**a)** $y=1.40x_1-28.42x_2-2989.75$

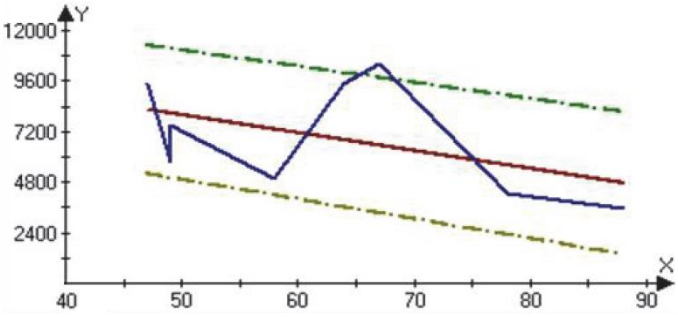
$$y=1.29x_1-3346.05$$
$$\underline{y}=1.29x_1-3997.49$$
$$\bar{y}=1.29x_1-2694.61$$




Amount of compensation paid to the injured ($y$) depending on the number of people with injuries ($x$)
*Kholodnaya Balka*

**b)** $y=-85.12x+12240.78\cdot$

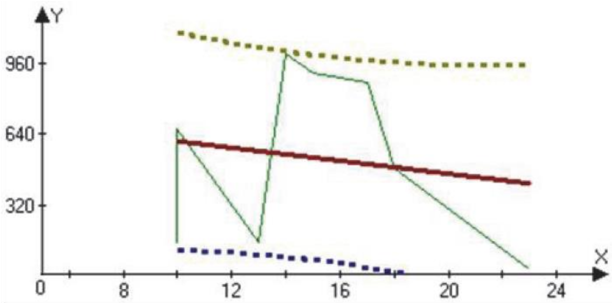
$$\underline{y}=-85.12x+12240.78-8988.14\sqrt{0.00065*(x-62.5)^2+0.125}$$
$$\bar{y}=-85.12x+12240.78+8988.14\sqrt{0.00065*(x-62.5)^2+0.125}$$




Amount of compensation paid to the injured ($y$) depending on the number of people with injuries ($x$)
*Gorniak-95*

**c)** $y=-85.12x+12240.78$

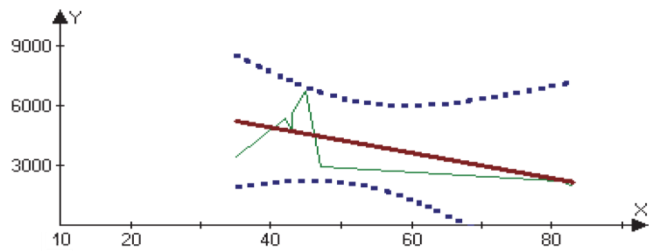
$$\underline{y}=-14.57x+752.44-1301.61\sqrt{0.00065*(x-15)^2+0.125}$$
$$\bar{y}=-14.57x+752.44+1301.61\sqrt{0.00065*(x-15)^2+0.125}$$




Amount of compensation paid to the injured ($y$) depending on the number of people with injuries ($x$)
*Lenin*

**d)** $y=-63.82x+7490.64\cdot$

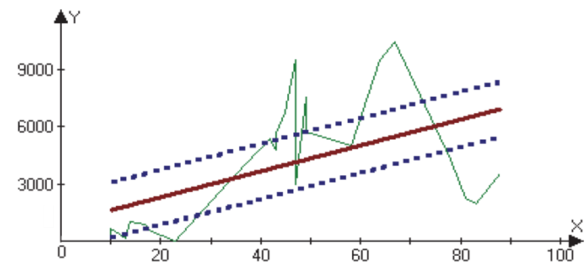
$$\underline{y}=-63.82x+7490.64-5863.92\sqrt{0.00065*(x-52.38)^2+0.125}$$
$$\bar{y}=-63.82x+752.44+5863.92\sqrt{0.00065*(x-52.38)^2+0.125}$$




Aggregated data – compensation paid to the injured ($y$) depending on the number of people with injuries ($x$) (linear and square functions)

**e)** $y=67.78x+933.49;$

$$\underline{y}=67.78x-508.23,$$
$$\bar{y}=67.78x+2375.2$$




**e)** $y=-3.49x^2+390x-4420.27$

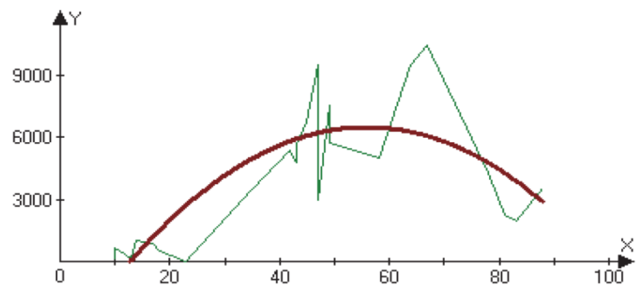



*Fig. 2. Graphic illustration of dependencies calculated in Table 5*

As it is possible to estimate the injuries rate in the mines, it is desirable to plan compensation payments to the injured people in the successive years (particularly next year).

The methods of parametric and non-parametric statistics were used to determine and analyze a number of dependencies. This way a comprehensive analysis can be performed to assess the process of industrial accidents. In the further research the following factors were taken into account:

- daily output of coal (tonnes per day);
- number of employees (people);
- number of injured employees (people);
- compensation for the injured (USD).

The obtained formulas and the criteria of their statistical assessment are demonstrated in Table 5. As it can be seen, the majority are linear or square values. All presented dependencies have, usually, significantly high values of correlation coefficients (two-dimensional or multi-dimensional correlation) and determination coefficients. In addition, they have a narrow range of confidence interval values, determined at the significance level of 95%.

Graphic interpretation of the obtained formulas is presented in Fig. 2a. Here it can be observed that the injuries rate shows a constant tendency to increase along with the increasing coal output (higher intensity of works).

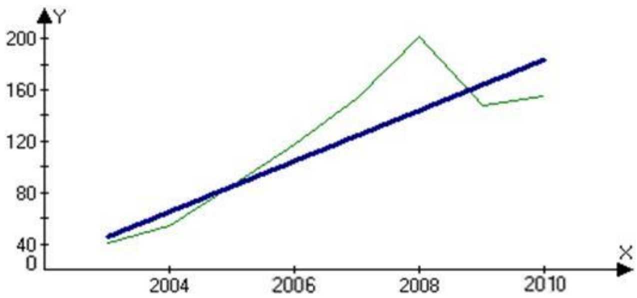
The dependencies between compensation payments to the injured and the number of people with injuries in mines (Fig. 2b, c, d) can be interpreted as linear and have a tendency to decrease with the increasing number of the injured, i.e. where the production process is stable, the majority of injuries are slight and non-fatal and their consequences are dealt with at low costs.

The dependency between compensation payments to the injured (linked data) and the number of people with injuries can be interpreted as linear (Fig. 2d) or non-linear (Fig. 2e), however, in this case it should be further investigated with the use of non-parametric statistics methods [2,3,4].

The amount of compensation paid to one injured person in the successive years has a linear character and an increasing tendency (Fig. 3 a, b, c – for particular mines; Fig. 3 d – aggregated data). It is also obvious (Fig. 3 a, b, c) that while in the Kholodnaya and Lenin mines the consequences of injuries are similar, the new private company Gorniak achieved much better results, i.e. fewer injuries and, generally, less serious ones.

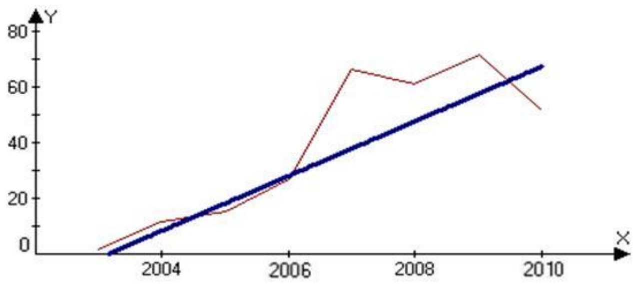
**Kholodnaya Balka**

**a)** $y(x) = 19.77x - 39554.19$



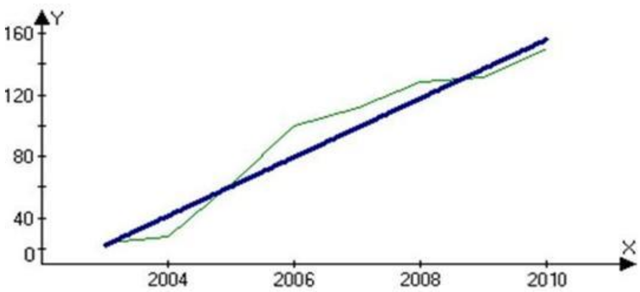

**Gorniak-95**

**b)** $y(x) = 9.82x - 19670.94$




**Lenin**

**c)** $y(x) = 19.13x - 38295.3$




**Aggregated data**

**d)** $y(x) = 18.19x - 36407.86$

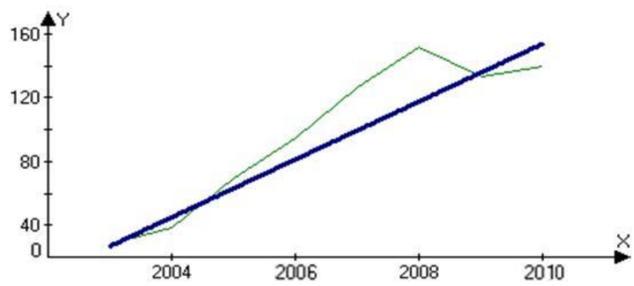



*Fig. 3 Amount of compensation paid to one injured person (y) in the successive years (x)*

## 2. CONCLUSIONS

The conclusion we can be draw from the above calculations is that the level of injuries increases proportionally to the intensity of mining works. As a consequence, the number of compensation payments increases too. It is interesting to note that the spending on accident insurance per one employee (average real severity of injuries) may be higher by more than twice in one mine than in the other, though their mining and geological conditions are very similar. Increasing production intensity requires to train the personnel in the range of safe working methods and to implement new, safer solutions [6]. The implementation of procedures that would improve the level of occupational health and safety, along with new mining technologies, is likely to lower the spending on compensation paid to people injured during work-related accidents. The statistical models presented in the article allow to estimate and predict the level of injuries and, consequently, the amounts of compensation paid to the injured. In the further research it would be advisable to take into account the level of the employees' awareness in the range of occupational health and safety, as well as the degree of progress in the applied mining technologies.

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