Analysis of the statistical correlation between the estimated value of individual risk and the hazard class of a hazardous production facility in the Russian Federation

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Abstract. This article describes industrial safety procedures that take into account a risk-based approach to industrial safety in the Russian Federation, and the specifics of their application. The analysis of 189 objects of I-IV hazard classes of LLC “Technical Environmental Consulting” (LLC “TEC”) was carried out and the statistical correlation between the estimated value of individual risk and the hazard class of a hazardous production facility was identified.

1 Introduction

In connection with the acceleration of rates and the expansion of the scale of industrial activity, the use of energy-saturated technologies and hazardous substances is continuously increasing. As a result, industrial safety issues are becoming increasingly relevant. The risk-based approach allows recognizing hazards, being in constant readiness to prevent the influence of negative factors and to combat their consequences [1-3].

In recent years, many important changes have occurred in the legislation of the Russian Federation. For example, the division of a hazardous production facility into hazard classes was introduced, the development of industrial safety management systems, the changes also affected expert activities [4,5].

The division of a hazardous production facility into classes provides for a varying degree of state supervision of objects, as well as the duty of the necessary procedures depending on the level of potential danger (table 1) [6-8].

It is worth noting that the hazard class of a hazardous production facility is assigned based on the quantity of hazardous substances present on the facility, and not on the magnitude of the risk on it. In this regard, it is necessary to analyze the statistical correlation between the estimated value of individual risk and the hazard class of a hazardous production facility [9-13].

2 Methods and results

To achieve the goal, the methods of statistical analysis were used: correlation analysis and analysis of the probability distribution.

For 189 facilities of LLC “TEC” hazard classes were determined, and individual risk indicators [1/year⁻¹] for personnel were taken from the company’s documentation. As a result, histograms of the distribution of objects in terms of individual risk for personnel at facilities of I-IV hazard classes were obtained (figure 1-4). The Y axis is the number of objects that, according to their indicators, fall into one or another range of risk values, along the X axis - the boundaries of the ranges.

To identify the statistical correlation between the values of the individual risk and the hazard class of a hazardous production facility we use the method of correlation analysis.

| Hazard Class | Development of industrial safety declaration | Development of an action plan for the localization and liquidation of accidents | Risk level |
|--------------|---------------------------------------------|--------------------------------------------------------------------------------|------------|
| I            | +                                           | +                                                                               | extremely high |
| II           | +                                           | +                                                                               | high       |
| III          | -                                           | +                                                                               | average    |
| IV           | -                                           | -                                                                               | low        |

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As a measure of the dependence between variables, the correlation coefficient \( r \) is used, which varies from \(-1\) to \(+1\). If the correlation coefficient is negative, this means that as the values of one variable increase, the values of the other decrease. If the variables are independent, then the correlation coefficient is 0. But if the correlation coefficient is not 0 (the variables are called uncorrelated), then this means that there is a relationship between the variables. The closer the value of \( r \) to 1, the stronger the dependence. The correlation coefficient reaches its limiting values of \(+1\) or \(-1\), if the relationship between the variables is linear [14].

Pearson Correlation Coefficient:

\[
 r = \frac{n \cdot \sum x \cdot y - (\sum x) \cdot (\sum y)}{\sqrt{n \cdot \sum x^2 - (\sum x)^2} \cdot \sqrt{n \cdot \sum y^2 - (\sum y)^2}}, \tag{1}
\]

where \( x \) and \( y \) are random variables.

We calculate the correlation coefficient, taking for \( x \) - the hazard class of a hazardous production facility, \( y \) - the value of the corresponding individual risk:

\[
r = \frac{189 \cdot 0.00486 - 433 \cdot 0.003045}{\sqrt{(189 \cdot 1143 - 433^2) \cdot (189 \cdot 3.5 \cdot 10^{-7} - 0.003045^2)}} = -0.32 \tag{2}
\]

The obtained coefficient indicates the presence of the opposite connection of weak force between variables.

However, it is worth noting that the low degree of correlation between the two quantities does not mean the absence of other non-linear dependencies. For example, a dependency can be complex non-linear in nature, which the correlation does not reveal [15,16].

For a more detailed study of the correlation between the values of individual risk and the hazard class of a hazardous production facility, an analysis of the probability distribution was carried out. Each probability distribution is determined by some parameters characterizing this distribution. Using appropriate statistics allows evaluating these parameters in a sample [17,18].

Probability density-function for normal distribution:

\[
f(x) = \frac{1}{\sigma \cdot \sqrt{2 \cdot \pi}} \cdot e^{-\left(\frac{(x - M[X])^2}{2 \cdot \sigma^2}\right)}, \tag{3}
\]

where \( x \) is a random variable; \( \sigma \) is the standard deviation; \( M[X] \) - mathematical expectation.

As a random variable, we take the logarithm decimal indicator of the individual risk \( \lg_{10}(R) \). The mathematical expectation is calculated as the average value of a random variable:

\[
M[\lg_{10}(R)] = \frac{\sum_{i=1}^{n} \lg(R)}{n}. \tag{4}
\]

The formula for standard deviation is:
The values of the mathematical expectation and standard deviation for the objects of each hazard class:

I: \( M_1[lg_{10}(R_i)] = -5.04, \sigma_1 = 7.64 \cdot 10^{-1} \)

II: \( M_2[lg_{10}(R_i)] = -5.39, \sigma_2 = 9.52 \cdot 10^{-1} \)

III: \( M_3[lg_{10}(R_i)] = -6.60, \sigma_3 = 1.02 \)

IV: \( M_4[lg_{10}(R_i)] = -6.62, \sigma_4 = 8.92 \cdot 10^{-1} \)

According to the obtained data, the values of probability density were calculated by the formula (2) and graphs were plotted of the density of the distribution of individual risk for objects of I-IV hazard classes (figure 5).

\[
\sigma = \sqrt{\frac{1}{n} \sum_{i=1}^{n} (lg_{10}(R_i) - M[lg_{10}(R)])^2}
\]  

(5)

Fig. 5. Density of distribution of individual risk values for objects of I-IV hazard classes.

According to the graph the average level of individual risk increases with an increase in the potential hazard of objects.

3 Discussion

The analysis of the obtained results revealed the following patterns:

1) with an increase in the hazard class of a hazardous production facility, the average arithmetic indices of individual risk increase;

2) with an increase in the hazard class of a hazardous production facility, the limits of the minimum and maximum risk, determined on the basis of statistics for each hazard class, increase;

3) in each group of objects of one hazard class there is the most common range of individual risk, i.e. each hazard class has the most likely range of risk indicators.

Thus, the use of statistical analysis methods in the implementation of a risk-based approach can improve the efficiency of industrial safety management of a hazardous production facility.

Knowledge of the statistical dependence of the calculated value of the individual risk on the hazard class makes it possible to more quickly recognize possible hazards, be in constant readiness to reduce or prevent the impact of negative factors and combat the consequences of this impact.

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