Study of Occupational Health Risks in the Irkutsk Region

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Abstract: The aim of this article is to study the statistical patterns of changes in the level of industrial risks in the Irkutsk Region and to identify the factors that have the greatest influence on these changes. In the paper, we used statistical analysis methods, such as retrospective analysis, construction of Shewhart control charts, and regression analysis. The retrospective analysis included the period of 2011-2017 and was carried out in the Irkutsk Region in general and by separate industries. The Shewhart control charts were constructed by type of injury in order to identify the randomness/systemic nature of the causes of damage to workers' health. The linear regression analysis was used to identify dependencies of the level of industrial injuries on the costs of labor protection measures. It was shown that, in the Irkutsk Region in general, the risks of injury and death of workers in the workplace tended to decrease during 2011-2017. But only since 2014 there has been an increase in the ratio of injuries to deaths, which indicates a real reduction in the severity of injuries. Statistical modeling using the construction of Shewhart control charts showed that there were systematic causes in respect to non-fatal injuries and, accordingly, the need to identify them. In terms of fatal injuries, we noted statistical risk controllability and natural variability inherent in random processes. Models of the linear dependency of the level of industrial injuries on the costs of labor protection measures revealed a high reverse causality between the risk of industrial injuries and the costs of training in labor protection. The results obtained indicate the need to increase the interest of employers in quality training in labor protection, as well as the importance of optimizing the costs to ensure occupational safety.

1. Introduction
The Irkutsk Region possesses sufficiently rich resources, and as a result, has well developed industry: forestry, mining, construction and transportation, a wide variety of manufacturing industries. All industries require careful monitoring in the field of occupational safety. In recent years, the region has seen a decrease in industrial injuries. However, this level still remains above the average for Russia, which speaks of existing shortcomings and the need to improve the labor protection management system and the occupational risk management system. A large number of papers are devoted to occupational risk assessment, including statistical methods of assessment and confirmation of their reliability [1-9]. The aim of this article is to study the statistical patterns of changes in the level of industrial risks in the Irkutsk Region and to identify the factors that have the greatest influence on these changes.

2. Methods
In the paper, we used statistical analysis methods, such as retrospective analysis, construction of Shewhart control charts [10], and regression analysis [11, 12]. The retrospective analysis included the...
period of 2011-2017 and was carried out in the Irkutsk Region in general and by separate industries based on data from the Irkutsk Regional Department of the Social Insurance Fund of the Russian Federation and the State Labor Inspectorate in the Irkutsk Region. The Shewhart control charts were constructed using the information from the Social Insurance Fund for the period of 2004-2017 by fatal injuries with a breakdown of the injured workers by quarters of the corresponding year, and for the period of 2010-2017 by non-fatal injuries, also with a breakdown by quarters. Based on the analysis of the constructed charts and the identification of points beyond the upper and lower boundaries on the chart of average values, we concluded whether the causes of damage to the health of workers were random/systematic. The univariable linear regression analysis was used to identify dependencies of the level of industrial injuries on the costs of labor protection measures [13]. As initial data, we used data of the Territorial Body of the Federal State Statistics Service for the Irkutsk Region on the costs of labor protection measures in the region as a whole, as well as on such costs as the purchase of personal protective equipment (PPE), training of workers in labor protection, costs of healthy and dietary meals (HDM), medical examinations of workers, as well as on the number of inspections by the State Labor Inspectorate. The significance of the models was assessed using the F-distribution; the constructed models were accepted with a significant probability of 95%.

3. Results
The calculated risks of injury and death of workers in the workplace in the Irkutsk Region in general showed an unstable decline in dynamics over the considered time period (Figure 1). We traced the dynamics of the ratio of the total number of industrial accidents to fatal accidents (Figure 2). It was revealed that in general from 2009 to 2017 there was an increase in the considered ratio, which indicates a real decrease in the severity of accidents. While in 2009 every 12th accident was fatal, in 2017 every 17th accident was fatal. But at the same time it is necessary to note 2013, which turned out to be the most disastrous in the labor protection of the Irkutsk Region - that year every 10th accident was fatal. Thus, it is still possible to conclude that the situation with industrial injuries in the Irkutsk Region in general has improved.

![Figure 1](image-url)
Assessment of the most significant industries of the Irkutsk Region in terms of the risk of employees’ death allowed us to identify the most traumatic industries and trace the dynamics of this risk over the past five years (Figure 3).

Figure 2. Dynamics of the ratio of the total number of industrial accidents to fatal accidents.

Figure 3. Dynamics of the risk of death in the workplace by separate industries of the Irkutsk Region.
It is shown that the greatest risk of death during the period under consideration is observed in the construction and the extraction of minerals: in the construction, the highest risk of death was observed in 2015 and amounted to $4.4 \times 10^{-4}/\text{year}$, in the mining industry - in 2016, when it amounted to $4.3 \times 10^{-4}/\text{year}$. It should be noted that, of all the selected industries, none has a steady tendency of reducing the risk of workers’ death. Moreover, in the manufacturing industry, the risk of workers’ death increased by 40% compared with 2013, and in the transport industry - more than 4 times compared with 2014.

There are various causes of industrial injuries; they are traditionally divided into technical, mainly related to equipment breakdown and failure, organizational, due to accidental and non-accidental human errors, and external, determined by the conditions in which the work is done. Shewhart control charts allow identifying the randomness/systemic nature of deviations of the production process from the reference conditions, including the process of labor protection. We constructed Schuhart control charts for the average values of the number of people injured in the workplace over the years (separately for fatal and non-fatal injuries). Yearly averages were calculated by quarterly values for the corresponding year. The chart for fatal injuries is shown in Fig. 4, for non-fatal - in Fig.5. The average charts show the average values of individual groups ($\bar{X}$), as well as three lines: central (average of averages ($\bar{X}$)) and two control limits – upper (UCL$_{\bar{X}}$) and lower (LCL$_{\bar{X}}$).

In Figure 4 it can be seen that the deviations of the points from the average lie within the upper and lower limits of fatal industrial injuries. This fact allows us to draw a conclusion about the statistical controllability of the process of protecting workers from death in the workplace, and to associate the changes in the curve with the natural variability inherent in random processes. To reduce the variability (width of the corridor between the limits) and/or the average value of the number of people injured in fatal industrial accidents, it is necessary to develop additional measures and improve existing measures to reduce fatal industrial injuries. The calculation showed that the average rate of change in the coefficient of the frequency of fatal accidents in the territory of the Irkutsk Region was - 0.003, that is, 2.5% per year.

![Figure 4](image-url)

**Figure 4.** Chart of averages for the control of fatal industrial injuries in the Irkutsk Region.

Looking at the chart of the average values of non-fatal industrial injuries, it can be assumed that there are systematic causes of workers’ injuries, since the deviations of some points from the average do not lie within the limits of the upper and lower limits of industrial injuries. Based on annually
published statistics on the causes of industrial injuries, it can even be assumed that systematic causes are rooted in the actions of people - the workers themselves or their supervisors - and are associated with some disregard of labor protection rules, in particular, formal (but significant for workers' responsibility) issues of work organization (especially work of increased danger). Therefore, we need additional motivation for safe work [14]. The average rate of change in the coefficient of the frequency of non-fatal accidents in the territory of the Irkutsk Region was -0.099, that is, 5.35% per year.

![Figure 5. Chart of averages for the control of non-fatal industrial injuries in the Irkutsk Region.](image)

To assess the significance of measures to improve labor protection in the Irkutsk Region, we used a univariable regression analysis between the risk of occupational injuries and the costs of labor protection measures. Table 1 presents the results obtained from modeling of the risk of industrial injuries from various items of labor protection costs. The significance of all models was assessed using the F-distribution; the constructed models were accepted with a significant probability of 95%.

**Table 1.** Results of calculating the models of a dual linear regression of the risk of industrial injuries from measures to improve working conditions.

| Measure                                              | Pearson correlation coefficient | Determination coefficient | Equation of linear regression                  | Linear relationship value |
|------------------------------------------------------|--------------------------------|---------------------------|-----------------------------------------------|---------------------------|
| Labor protection measures in general                 | -0.83                          | 0.69                      | \( y = 0.002822 - \frac{0.000000543}{x} \)     | High                      |
| Costs of PPE                                         | -0.53                          | 0.28                      | \( y = 0.00074 - \frac{0.000000056}{x} \)      | Noticeable                |
| Costs of training in labor protection                | -0.79                          | 0.62                      | \( y = 0.000706 - \frac{0.000029}{x} \)        | High                      |
| Costs of medical examinations                        | 0.41                           | -                         | \( y = 0.000564 + \frac{0.00000022}{x} \)      | Direct (no influence)     |
| Inspections by the State Labor Inspectorate         | -0.39                          | 0.15                      | \( y = 0.000685107 - \frac{0.000000012}{x} \)  | Moderate                  |
| Costs of healthy and dietary meals                   | -0.18                          | 0.034                     | \( y = 0.000739179 - \frac{0.0000011}{x} \)    | Weak                      |
The results obtained suggest that the costs of labor protection measures in general have a high reverse causality. The greatest significance of the reverse causality of the risk of industrial injuries in the Irkutsk Region is observed in conjunction with training in labor protection of workers and employers, which indicates the importance of this measure in reducing industrial injuries. The least effective of the measures considered are the costs of healthy and dietary meals, which, of course, is more logical to associate with the influence of working conditions, rather than with industrial injuries. The costs of medical examinations carry only a direct linear relationship, which indicates the absence of a noticeable effect of periodic medical examinations on the level of industrial injuries, which in itself can be the subject of independent research.

Thus, we are talking about the need to increase the interest of employers in quality training in labor protection [15, 16].

4. Conclusion
The results obtained indicate a reduction in the risk of industrial injuries and death of workers in the Irkutsk Region in general. At the same time, in none of the considered industries there is a steady decrease in the risks of death, and in some industries, such as manufacturing and transport, the risks of death have increased over the past five years. It is shown that there are systematic causes of industrial injuries and additional motivation is needed for both employees and employers to eliminate them. We found that the costs of labor protection measures in general had a significant impact on the reduction of industrial injuries, with the greatest impact made by the costs of training in labor protection, therefore, it should be concluded that there is a need to increase the interest of employers in quality training in labor protection, and that it is important to optimize the costs of measures ensuring occupational safety.

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