Modeling professional risk based on the analysis of Workplace Conditions Assessment (WCA) to improve the safety of production activities

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Abstract. The article discusses the problem of determining safe work experience in conditions of increased intensity of hard work. It is especially relevant in construction industry. The need for an objective analysis of industrial accidents is an urgent task not only for the prevention of injuries, but also for improving environmental safety, interpreted as occupational risk management in order to protect the health of people of active working age. The research methodology was based on the analysis of the characteristics of the occupational diseases risk, depending on the level of existing harmful production factors, as well as the length of service. Occupational risk is directly related to the dynamics of changes in harmful and hazardous production factors during an employee's work experience. This risk gradually increases nonlinearly over the course of the employee's work experience, and in the experience sector the risk begins changing at an increasing rate. The new system for assessing working conditions introduced in 2014 in Russia, although it helps to reduce the annual increase in risk, but cannot provide completely environmentally friendly and safe working conditions and acceptable risk (R). The environmental safety of production activities is a big question and is at high risk in the construction industry, in particular due to the huge number of concealment of occupational injuries, violations of the regenerative capacity of the human body, as well as the extension of the retirement age to 65 and 70 years. Therefore, it is required to introduce a mechanism (model), providing a real system for assessing working conditions.

1 Introduction

The share of manual labor is quite high in construction sector, and hard work is one of the factors of increased risk, therefore, the definition of safe work experience in conditions of increased difficulty of work is especially important in construction industry [1-5]. This topic is the subject of many Russian official guidelines and methodological manuals developed for assessing occupational health risks of workers (for example, URL:

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Once in a while, statistical data on industrial injuries and occupational diseases are the main indicators in assessing the measures taken to improve industrial safety. Especially, when it comes to hazardous and harmful production conditions. In the Russian Federation, such organizations are responsible for data on injuries as: Rostrud (Russian Service of Labor), Rosstat (Russian Statistical Service), SIF (Social Insurance Fund), and Rostekhnadzor (Russian Technical Supervision). Each of these organizations keeps own records of statistics according to certain principles. For example, Rostrud takes into account accidents and industrial injuries registered on the bases of requests and complaints from employees themselves. While Rosstat takes into account accidents, only in the case when they were provided by employers. Rospotrebnadzor, in turn, pays great attention to occupational diseases, and the SIF focuses on insured accidents. The presented data can be considered, both separately for each component, and all together to draw up an overall picture of the safety level of a particular production branch. As a result, the need for an objective analysis of industrial accidents is an urgent task not only for the prevention of injuries, but also for improving environmental safety, interpreted as occupational risk management in order to protect the health of people of active working age [6-8].

Identical data from different organizations can differ significantly in numerical values, which leads to misinformation about the state of affairs in labor protection. So, for example, information about 5-6% of the total number of incidents at work is in the focus of official statistics. Under these conditions, it is important to investigate and register minor and moderate injuries, which may subsequently lead to an accident. It seems important to create an electronic database with information about each accident, regardless of its outcome. To do this, it is necessary to compare the totality of the received data with identical ones, but where to get them from?

There are two different options. The first is to compare data with last year's results and draw a conclusion about the effectiveness of the measures taken in relation to previous years. The specified option is intended to track the trend and clearly see how the injury indicators change from year to year. But due to inaccurate statistical information on labor protection provided by Rostrud (analyzes data on injuries at work, but in the case of severe injuries with fatal outcomes, single incidents are not registered, only group incidents), Rosstat (collects and analyzes data on all types of accidents in production at large and medium-sized enterprises, at small only selectively in 12 types of economic activities, excluding financial activities, public administration, military security, social insurance, education and some others), the FSS (records only insured events) and a number of other state organizations, there is no confidence in the accuracy of accounting. Moreover, there is no way to understand how effective the current measures are. For example, if we compare the data on victims in the construction sector, they differ significantly: 8.5% (Rosstat) and 23.2% (Rostrud). In 2019, according to statistics from the Social Insurance Fund (FSS), there were 1527 fatalities. According to Rostrud data, work-related fatal injuries affected 1613 workers (Fig. 1).

Obviously, the above statistics complicates the effective use of the first option for analyzing occupational injuries.

The second option of the analysis is more informative due to the comparison with the data obtained in other countries. It is quite effective, because many European countries that are members of the International Labor Organization have a low rate of reduction in overall industrial injuries (for example, in 2016, in Germany, the number of injured people was 877.1 thousand by 40.1 million workers against 39.8 thousand industrial injuries in Russia for 44.4 million) (URL: http://www.ilo.org). This circumstance once again emphasizes on
all the implausibility of Russian statistics. In the Western countries, the risk of fatal accidents at work is reduced by modernizing production and reducing a number of workers employed in hazardous and harmful conditions. Indeed, in Germany, between 1990 and 2015, the proportion of fatal injuries fell from 0.08 to 0.05% (URL: http://www.ilo.org/ilostat/faces/home/statisticaldata?_afrLoop=680869279925113&_adf.ctrlstate=w7otyfthy_4).

![Fig. 1. Injury statistics data (Social Insurance Fund).](image)

It is worth noting once again the principle, on the basis of which the effectiveness of the measures taken is achieved: reducing the number of workers in hazardous industries, rather than protecting them with personal protective equipment. Since 2007, the severity of industrial accidents in Russia has only increased every year. In 2016, economic losses from compensation in connection with accidents and occupational diseases caused by the state of production and labor protection at enterprises amounted to 1.53 trillion rubles, or 1.8% of GDP (URL: http://eisot.rosmintrud.ru/attachments/article/47/results_2016.doc).

Despite the annual increase in labor protection costs, the number of jobs with unsatisfactory working conditions has not decreased. The scope of labor protection expenditures per employee shows that the costs are mainly spent on the system of special assessment of working conditions (SAWC), medical care, the purchase of overalls and personal protective equipment. According to the Ministry of Labor and Social Protection of the Russian Federation (URL: https://rosmintrud.ru/docs/mintrud/analytics/137), losses and costs associated with the unsatisfactory state of working conditions amount to 1.6 trillion rubles annually, of which: economic costs due to the loss of working time make up 1.31 trillion rubles (84.5%); expenses for compensation and provision of personal protective equipment pick up 141.3 billion rubles (9.1%); early pension payments are estimated at 49.9 billion rubles (3.2%); insurance payments reach 51 billion rubles (3.2%).

Whatever the personal protective equipment is, the measures aimed at preventing deaths and taken by European countries in labor protection are really effective. They should be introduced in Russia [9]. Let us consider the methodology of the International Labor Organization (ILO) regarding the reliability of statistics on industrial accidents in countries with imperfect accounting. For the already indicated reasons, Russia can be classified as such a country. The essence of the technique lies in the fact that fatal injuries are recorded better than other injuries, therefore, fatalities should become the basis for subsequent calculations of the probable total number of injured persons [10]. The transition from the number of deaths to the total number of injured persons is realized through a ratio
confirmed by many years of experience in Western European countries, the USA, Canada, and Japan. It averages from 500 to 1000 injuries per one fatal injury and shows the number of injuries on average corresponds to one fatal accident at work. It should be emphasized that the introduction of this technique cannot become a panacea for reducing the proportion of jobs that do not meet sanitary and hygienic standards. In addition, there is an explanation for this. Changes in the methodology regarding the assessment of working conditions (the abolition of the certification procedure for workplaces in accordance with Federal Law No. 426-FZ dated 28.12.13 “On special assessment of working conditions”) led to the fact that the standards for a number of production factors in Russia, at first glance, decreased significantly. For this reason, many jobs and working conditions that were previously considered harmful and/or dangerous were classified as acceptable (but, it is interesting that the proportion of deaths in the total number of victims in Russia increased from 1.9% in 1990 to 4.8% in 2016) [11].

Since 2015, although the indicator of the share of workers employed in workplaces that do not meet sanitary and hygienic requirements has been decreasing, however, according to experts, this process is associated with the introduction of a new system of special assessment of working conditions. A decrease in the officially registered indicators of the frequency of accidents against the background of an extremely high proportion of enterprises recognized as dangerous and unfavorable for the health of workers seems to be unlikely [12]. In connection with the above, the purpose of the article is to show the inability of SAWC not only to prevent (compared with the previous system of certification of workplaces for working conditions), but at least to weaken through compensatory measures (reduced working hours, annual additional paid leave or monetary compensation for them, as well as increased wages) negative impact on the health of workers of harmful and dangerous factors of the production environment and the labor process [10]. In the course of the study, the following tasks were solved: (1) the concept of risk in occupational safety and health was analyzed and (2) the reasons for the increase of occupational risk (OR) and the risk of occupational disease (OI) was clarified.

2 Materials and methods

The research methodology is represented by the following algorithm. In the first stage of studying the topic, a method of contextual analysis of the problems associated with professional risk, generated by unfavorable factors of production was applied. The inconsistency of official statistics of professional diseases with respect to an expert assessment was established, according to which their potentially possible number significantly exceeds a claimed one. Further analysis of the problem showed that the introduction of the SAWC system, which replaced the former procedure for workplaces certification, could not stop the growth of industrial accidents in Russia. Consideration of the Methodology of the International Labor Organization (ILO) regarding the truthfulness of statistical data of industrial accidents in countries with imperfect accounting has led to the conclusion that fatal injuries registered better than the remaining injuries is the basis for any reliable calculations of the likely total number of injured persons. The transition from the number of those who died to the total number of victims in Russia is represented by the relation 1:22 (1: 1732 in Germany) and indicates a huge "gap" in the data array, by which official statistics operates. According to N. Bor, K. Gödel, A. Tarsky, one of the most important principles of the contextual approach is the complementarity principle of contexts that postulates the impossibility of describing any phenomenon in the frameworks of the only single concept of official statistics and the need to combine additional descriptions in various theoretical contexts. In the second stage of the study, the concept of professional risk was taken as an additional context. In this regard, the features of the OI
risk and their dependence on the level of existing harmful production factors, as well as work experience were analyzed. Thus, the OR is directly related to the dynamics of changes in harmful and hazardous production factors during the employment experience of the employee, which was reflected in modeling acceptable risk in professional experience of employees before their retirement. The identified patterns of professional risk occurrence are presented in formulas and drawings.

3 Results and discussion

Modern labor protection management systems are based on a risk-based principle. In the sphere of security, the term risk has two wording:

1. In Labor Code of the Russian Federation dated of 30.12.2001 N 197-FZ, the risk is defined as a combination of the probability of an event and its consequences (an injury, OI, an accident, etc.) (URL: http://www.consultant.ru/document/cons_doc_LAW_34683/).

2. In Federal Law "On compulsory social insurance against accidents at work and occupational diseases" dated of 24.07.1998 N 125-FZ, OR is defined as the likelihood of damage (loss) of health or the death of the insured, associated with the fulfillment of their responsibilities for the employment contract and in other cases established by the legislation (URL: http://www.consultant.ru/document/cons_doc_LAW_19559).

The risks of the occurrence of industrial diseases and accidents are differentiated. The derivation of an element responsible for assessing the consequences of the implementation of negative events in the concept of risk is due to the fact that that meaning of risk came to safety from the insurance system. In insuring, possible events are differentiated for damage to calculate insurance costs that employers should pay when insuring employees against accidents and/or OI. In labor protection, legislative risk categories specified for each sector of the economy are used for insurance, which do not provide differentiation of the type of workplace. The definition of OR from the Labor Code can be used for planning labor protection activities, which makes it possible to take into account the impact of hazardous and harmful production factors to evaluate the OR indicators. It is obvious that the presence of a large number of definitions and indicators of OR complicates the choice of the main indicator, quite accurately reflecting the advantages of SAWС, the legally introduced in 2013.

To determine the long-term effect of labor protection activities, it is necessary to have the possibility to receive forecast values used for strategic planning [13-16].

For all kinds of economic activity, factors of the production environment became the main harmful and hazardous industrial factors affecting workers. So, in 2020, 23.6% of employees (every fourth) were subjected to their effects in the construction industry. The factors of the labor process (difficulty and intensity) were followed by the significance of the negative impact on workers. In 2020, the share of workers engaged in hard work in construction was 15%. The number of employed in construction in the same year in jobs related to the intensity of the labor process, was 8.1% [9]. Since 2014 to 2020, the introduction of the SAWC procedure has not led to a radical change in the proportion of workers engaged in work with harmful and hazardous working conditions, but significantly affected the structure of hazardous and harmful production factors affecting employees. In the first place there were the hard work, various types of noise, vibrations, aerosols predominantly fibrogenic action etc. Separate indicators characterizing the harmful and dangerous factors of the production environment and the intensity of the labor process, in general were excluded from the SAWC (for example, "Heating microclimate" and "Cooling microclimate"). Thus, as a result of the SAWC procedure introduction, (1) the factors of the production environment associated with a periodic change in working conditions due to the change of the geographical location of construction objects; (2) difficulty and intensity of
construction work; (3) impact of harmful and dangerous factors on the health of employees are essential for strategic planning in the sphere of construction security [17].

Table 1 presents the proportion of jobs that do not meet the established standards for individual production factors at construction enterprises (URL: http://rospotrebnadzor.ru/upload/iblock/0b3/gosudarstvennyy-doklad-2020.pdf).

**Table 1.** Quota of workplaces that do not meet the standards of working conditions for individual production factor and labor process in the construction industry of the Russian Federation.

<table>
<thead>
<tr>
<th>Factors</th>
<th>Part of workplaces that do not meet the conditions of labor in construction, %</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>2018</td>
</tr>
<tr>
<td>Large difficulty</td>
<td>20.1</td>
</tr>
<tr>
<td>Noise</td>
<td>13.9</td>
</tr>
<tr>
<td>Labor intensity</td>
<td>7.5</td>
</tr>
<tr>
<td>Chemical factor</td>
<td>7.4</td>
</tr>
<tr>
<td>Vibration</td>
<td>7</td>
</tr>
<tr>
<td>Microclimate</td>
<td>5.9</td>
</tr>
<tr>
<td>Light medium</td>
<td>3.9</td>
</tr>
<tr>
<td>Aerosols of predominantly fibrogenic action</td>
<td>3.8</td>
</tr>
<tr>
<td>Non-ionizing radiation</td>
<td>1.6</td>
</tr>
<tr>
<td>Ionizing radiation</td>
<td>0.5</td>
</tr>
<tr>
<td>Biological factor</td>
<td>0.4</td>
</tr>
</tbody>
</table>

It should be noted that the high percentage of workers in the construction industry with unsatisfactory working conditions is due to: increased dust and gas content of the working area; high percentage of manual labor (up to 50%); depreciation of technological equipment (up to 50-65%); increased sound levels in workplaces (excess to 10-20 dBA); reduced air temperature (5-10°C below normative); low mechanization of labor-intensive technological processes (35-50%) (URL: https://rosmintrud.ru/docs/mintrud/alanalytics/137).

Dynamic change in these factors is reflected in the OR indicators. Their value changes randomly due to hazardous factors, as it depends not only on changes in the state of working conditions, but also on the behavior of staff at the workplace, time of year, day, etc. The value of OR indicators is characterized by slow, gradual development. With the growth of labor experience, the functional health indicators change gradually and linearly: the risk indicator first changes slightly, then changes with increasing speed [18]. The risk features of the OI occurrence include its dependence on the level of existing harmful production factors, as well as the experience [19]. Thus, the OR is directly related to the dynamics of changes in harmful and hazardous production factors during the employment experience of the employee [20].

The risk of OI during the employment experience of the employee gradually increases nonlinearly, which can be called the accumulation of OR. In the experience zone, the risk begins to change with increasing speed (Fig. 2).

![Fig. 2. Risk dependence on work experience [18].](image-url)
Three OI risk zones can be distinguished in the dynamics of employment (Fig. 3).

Fig. 3. Risk dynamics during employee's work experience.

In the safe area, due to the short work experience (5 years), there are no reasoned data on health deterioration yet, but a certain attention is required. In the border zone (5-8 years), health deterioration exceeds the permissible level and becomes dangerous, close monitoring is required. In a danger zone at a fairly large experience (after 8 years), the OI frequency becomes high and unacceptable and the risk exceeds the value of 0.5. Thus, OR intensively accumulates. Its intensity can be assessed in terms of annual growth [21, 22]:

\[ R_i = R_{i-1} + \Delta R_i. \]  

(1)

where \( R_i \) is the OR, accumulated by a worker during the \( i \) years of labor activity under the conditions of the production medium; \( \Delta R_i \) is the increment of OR on the \( i \)-th year of labor experience. The initial value of OR (\( R_0 \)) is given by the method of expert assessments for each specific enterprise of the construction industry. An annual increase in OR must be provided at such a level so that for a period of safe experience the accumulated OR did not exceed acceptable values. It is assumed that accumulation of the risk begins during the primary arrival at the workplace not from the zero value, but from some background initial value (\( R_0 \)) due, for example, a person's life, a place of residence or place of previous work. Thus, the safe state of the production environment can be expressed through an acceptable risk by the following formula [5]:

\[ R_0 + \sum_{i=1}^{T_{\text{safety}}} \Delta R_i \leq R_{\text{acceptable}}. \]  

(2)

where \( R_0 \) is the initial OR; \( T_{\text{safety}} \) is a safe work experience in the specified conditions of the production environment.

The concept of risk acceptable with respect to the difficulty of work correlates with the principles of the task of extremely permissible levels, which at 8 hours of work, except the weekend, (but not more than 40 hours per week) during the entire working experience do not cause occurrences of diseases or deviations in the health status of workers [19]. Such labor protection measures that have ensured the non-exceedance of the acceptable value of OR during the work experience before reaching the age for retirement will be recognized as effective to reduce labor difficulty. For example, for the oilfield worker, an acceptable risk is ensured (1×10^{-3}) for professional groups, while maintaining the technology of work and working conditions, and if the work experience will last 3-4 years [8].
The normative period of OR accumulation is determined using the following considerations:

1. The accumulation period to an acceptable OR value corresponds to the value of the work experience, in which the employee has reached a retirement age. In other words, the work experience of the personnel is determined before the retirement age (retirement experience in 45 and 40 years old in men and women, respectively) [20].

2. If the accumulation period of OR (to an acceptable value) does not ensure the beginning of retirement age of an employee without OI, it is necessary to determine the experience at which an acceptable OR (safe experience) is achieved. To establish a safe work experience, the employers are guided by the requirement of the Pension Insurance Act on the maximum experiences of work in particularly harmful working conditions and a reduction in retirement age. If workplaces in the construction site are considered, for which the maximum work experience and the state of labor conditions does not allow for acceptable OR during the entire employment experience, it is necessary to establish the value of the work experience at which there is no excess of the acceptable risk. There is the following principle of establishing a safe work experience in labor medicine: "work experience exceeding half of the average period of development of an occupational disease in a given profession is considered a significant risk factor" [23].

The effectiveness of measures for labor protection when using OR accumulation logic is presented in Fig. 4 [24].

![Fig. 4. Evaluation schemes of unacceptable risk for labor protection: a) without using the logic of OR accumulation of, b) using one.](image)

As can be seen from the figure, in the second variant (b) using the OR increment logic, a new variable appears: \(R_{\text{unacceptable}}\) (the value of unacceptable risk). Accounting for unacceptable risk allows you to change the strategy of occupational safety measures and achieve such an annual increase in the professional risk \(\Delta R_{\text{safety}}\), in which the normative safe experience \(T_{\text{safety}}\) corresponds to \(T_{\text{retirement}}\) and employees reach retirement age. Reducing the annual OR increment by value equal to the ratio of the actual safe work experience to the value of a safe work experience corresponding to the regulatory working conditions is expressed in the following formula:

\[
\frac{T_{\text{safety}}}{T_{\text{retirement}}} = \frac{\Delta R_{\text{safety}}}{\Delta R}, \tag{3}
\]

It is important that the annual increment \(\Delta R\) provides a safe work experience \(T_{\text{safety}}\). Thanks to the effective events, the ratio of the value of acceptable risk \(R\) before the
retirement work experience to the value of acceptable risk up the beginning of the retirement work experience shows how actually an effective strategy will ensure a reduction in the annual incremental risk. The less this increment is, the more effective is the strategy to improve the conditions and protection of labor. The problem arises of developing mechanisms for determining the increment of OR and predicting it during the work experience of workers by the factor of labor difficulty. However, without referring to the implementation of this task in a small article, it should be emphasized that the reduction of the contingent of workers in respect of whom it is required to carry out SAWC procedure both as a whole and for individual hazardous and harmful production factors, as well as a change in the methodology for evaluating working conditions in which there were, in particular, certain indicators characterizing hazardous factors of the working environment and the intensity of the labor process are excluded from the SAWC, although they contribute to the decrease in the annual increment ΔR, but cannot ensure safe duration of work experience of workers and an acceptable risk R until their retirement. With the introduction of the SAWC procedure, the indicators used to assess the difficulty of the labor process have not changed either quantitatively or qualitatively. Their impact on the reduction of the proportion of workers engaged in hard work, as well as in work with harmful and hazardous working conditions, cannot be reliably established only by reducing the contingent of workers in respect of whom the working conditions are evaluated. Yes, and this reduction in the proportion of workers, one can say, did not affect the change in the structure of hazardous and harmful production factors affecting employees [11].

As already mentioned, the number of accidents per 100,000 workers in Russia is less (than in the UK by 6 times, with respect to Italy by 10 times, Germany by 18 times, France by 24 times, Spain by 25 times), but the number of deaths on production per 100,000 employees in Russia is the highest compared to the countries of the European Union. Thus, the average indicator of the considered relationship between fatal injury and the total number of accidents is 1:22 (1: 1732 in Germany) [25]. A significant number of accidents at the enterprises of the Russian Federation is hidden from registration and accounting, despite the decline in officially recorded cases of industrial injuries, including fatal ones. Calculations conducted by the Research Institute of Labor Medicine of the Russian Academy of Medical Sciences show the estimated specifications of the number of patients with occupational diseases from the number of employees undergoing compulsory medical examinations due to harmful working conditions is about 7.7%. This is more than 60000 people and clearly exceeds the officially recorded annual statistics, fluctuating within 9000-12000 cases per year [8]. Since employers have no funds to modernize the production and it is easier for them to provide financial compensation for the difficulty of the labor process, it is impossible to ensure safe work experience of workers and acceptable risk R before their retirement not only in dangerous industries in Russia, but also in the construction industry, in particular. It must also be remembered that in the area of work experience, the health risk of workers begins to change at an increasing rate, regardless of the type of production. In addition, the inconsistency of the labor intensity to the restorative ability of the body is the most common, frequent and important cause of chronic fatigue and associated health risks, which is generally not taken into account by employers during the implementation of construction projects [18].

4 Conclusion

The following conclusions can be drawn as a result of the SAWC analysis, based on the factors of increased risk at the production and determination of the safe work experience in conditions of increased difficulty of work.
In the SAWC procedure compared to the previous order of certification (accreditation of workplaces under labor conditions), the contingent of employees has been reduced, for which the working conditions are evaluated for compliance with the requirements of labor protection both in general and on certain hazardous and harmful production factors. The method of evaluation of working conditions has been changed, during which individual indicators characterizing the harmful and hazardous factors of the production environment and the employment process were excluded from the assessment. Significantly, understated statistical data on industrial injuries is a consequence of SAWC imperfections. Paying financial compensation to employees, employers seek to conceal the registration of accidents. If the employer is not motivated to create favorable working conditions at his enterprise, then the result is the payment of insurance premiums in an increased amount. The highest premium size (40%) is obtained by insurers who have no interest in conducting measures to reduce the level of industrial injuries. The ratio indicator between fatal injury and the total number of accidents in Russia exceeds almost 1000 times the indicators of the European Union countries, which indicates the inaccuracy of statistical data on cases of industrial injuries, including the fatal ones. The essential discrepancy between the actual safe work experience to the value of the safe work experience in the framework of normative working conditions is one of the main reasons for the ineffectiveness of measures to reduce the difficulty of work.

The risk analysis in the area of safety and labor protection has shown that the safe work experience of workers and the acceptable risk R before their retirement cannot be provided only by reducing the contingent of employees, although the indicated decrease contributes to the annual small increment ΔR. For the less this increment is the more effective the strategy for improving the conditions and protection of labor is. However, under conditions, when the structure of hazardous and harmful production factors affecting employees has not changed neither quantitatively nor qualitatively, the gap between safe experience and pension raises (i.e., the value of unacceptable risk).

The professional risk model, created on the basis of the SAWC procedure showed that the risk directly related to the dynamics of changes in harmful and hazardous production factors during the worker's work experience, in the homosphere zone increases sharply and makes the high risk of occupational diseases unavoidable. The non-exceedance of the acceptable value of OR during the work experience until reaching the retirement age becomes impossible. Environmental safety of production activities is under great question, in particular, in the construction sector.

References

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