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Study of the harmful factors influence on the occupational risk level: the example of the Ukrainian mining industry

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ABSTRACT

Purpose: The choice of preventive measures and labour protection equipment should be justified taking into account the occupational risk. For objective reasons, existing approaches do not provide an opportunity to justify the choice of the necessary measures, which best reduce the occupational risk level. Consequently, an effective methodological approach to justify preventive measures is required, since the level of risk in mining enterprises is still high, especially in developing countries and countries with weak economies. The current research is devoted to solving this urgent scientific problem.

Design/methodology/approach: Construction of mathematical models based on accumulated statistical data on the values of production factors using polynomial regression, which is justified by the simplicity of computational algorithms and the clarity of the results obtained.

Findings: On the example of the Ukrainian mining industry, it was found that to reduce occupational risk; the most effective is to change the operating mode of the equipment and rational planning of working hours, but not measures to reduce the dust concentration.

Research limitations/implications: The study is focused on the mining industry; a methodological approach and a mathematical model are proposed for specific working conditions at Ukrainian mining industry.

Practical implications: The proposed approach makes it possible, based on statistical data, to quickly and reliably select the most effective measures to reduce the industrial risk level.

Originality/value: A feature of the proposed approach to reducing industrial risk is a comprehensive accounting of data on factors affecting occupational risk, the construction of mathematical models and the use of modelling results when planning measures to improve working conditions.

Keywords: Mining industry, Occupational risk, Statistical data, Harmful factors, Dust

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INDUSTRIAL MANAGEMENT AND ORGANISATION

1. Introduction

Among the branches of the extractive industry in Ukraine, one of the leading places belongs to the mining, whose enterprises produce minerals from quarries, and which are dangerous for the environment [1,2] and the health and life of workers [3-5]. The mining industry has been identified by the National Institute for Occupational Safety and Health (NIOSH) as a priority sector in the National Occupational Research Program (NORA) to identify and provide intervention strategies for health and safety issues [6].

Natural stone resources are of particular economic importance among the mineral raw materials of Ukraine, and Ukrainian granites have established themselves as a high-quality, proven natural processing material for years.

Analysis of the technology of work on the extraction of granite allows us to determine the following stages: the separation of monoliths from the massif is achieved by the formation of cutting and dividing slots at the ends of the monoliths with a diamond wire machine in combination with portable pneumatic perforators; the division of monoliths into smaller parts and blocks is carried out by the borehole method using pneumatic perforators and hydraulic wedges, non-explosive destructive agents and metal blades [7].

The separation of the monolith from the massif is carried out in one or two stages. In a one-stage scheme, the blocks are separated from the massif directly at the bottom by the mechanical drilling-wedge method, as well as by the borehole method using non-explosive destructive means and blades. In a two-stage scheme – by the formation of cutting slots along the ends of the monolith and the line of its separation from the massif, followed by filling the monolith onto the bottom of the ledge and dividing it into blocks of the required sizes. The separation of monoliths from the massif is carried out taking into account the general fracturing of rocks at the site of work. The use of natural cracks makes it possible to reduce the amount of work on the creation of insulating cracks.

Drilling robots. During the extraction of granite blocks, the blast-hole method of drilling is used. The holes in the face are positioned along the intended rebound line using a detonating cord and black powder. The borehole diameter is 32-36 mm. The distance between the holes in the row is 15-25 cm. The holes are not drilled in depth to horizontal cracks at (10-20%) of the bench height to keep the lower part of the granite from spreading cracks during blasting operations. The holes are drilled using rock drills.

Vertical transport. The blocks are loaded into dump trucks by a self-propelled jib crane. Loading work is carried out by a crane operator and a rigger from among the workers involved in the extraction of blocks. Large blocks and waste from mining operations can be loaded into dump trucks with a single-bucket excavator. Planning work on quarry and access roads, industrial site, dumps, as well as on the movement of blocks and a number of other works are carried out using a bulldozer.

The ***list of professions*** involved in a full-time career is as follows: stone blocks and slabs crushing worker; excavator driver; crane operator; mining foreman, electric and gas welder.

In a production environment, workers need measures to protect against the negative effects of dust [8], tool breakage [9], vibration [10], heat radiation [11] and other production factors. However, the proposed and implemented preventive and protective measures are not always timely and effective [5].

Obviously, the choice of preventive measures and labour protection equipment should be justified taking into account the occupational risk [12,13]. Consequently, an effective methodological approach to justification and selection of measures is required. The essence of problem is as follows. Existing approaches are based on a comprehensive accounting of statistics of injuries, equipment characteristics, technological process features, compliance of buildings and structures with regulatory requirements. However, the results of these assessments do not provide an opportunity to justify the choice of the necessary measures, which best reduce the occupational risk level. So currently, the creation of an effective methodological approach is an urgent scientific task, since the level of risk in mining enterprises is still high, especially in developing countries and countries with weak economies.

2. Material and methods

The workplaces of open pit workers are assessed. The influence of each production factor on the occupational risk level was quantified. For this, mathematical modelling was applied. Mathematical models were built on the basis of accumulated statistical data (values of production factors). To develop mathematical models, the authors used polynomial regression. This is due to the greater simplicity of computational algorithms and the absence of the need for specially trained specialists, such as for the use of soft computing methods [18-20]. In addition, it is easy to interpret the results obtained, which contributes to the spread of the method to solve a wide class of problems in the field of labour protection.

The construction of models using polynomial regression is based on the properties of functional dependencies, which can be formulated as follows: with a gradual increase in the complexity of the models (the degree of the polynomial), the magnitude of the errors (approximation error, forecast error) decreases monotonically. It is this property that makes it possible to obtain a model of a given accuracy.

$$\begin{aligned} xr &= a_0 + a_1 C; \\ xr &= a_0 + a_1 C + a_2 C^2; \\ xr &= a_0 + a_1 C + a_2 C^2 + a_3 C^3; \\ &\dots \end{aligned} \tag{1}$$

where xr – the weighting factor of the factor that determines its impact on occupational risk; C – the degree of harmfulness of the factor; a_0, a_1, a_2, a_3 – constant coefficients of the model (determined by calculation).

On the basis of the collected statistical data the estimation of working conditions of workplaces on a quarry on extraction of granite on indicators of factors of the production environment for a profession of ways of plates and blocks is resulted (Tab. 1).

Let us estimate the value of the degree of dust hazard per shift. The degree of hazardousness of dust, depending on the value of exceeding the standards, is established in accordance with [21]. At the workplace, according to Table 1, the actual level of dust concentration is 13.6 mg/m^3. The duration of the factor is 87.4% of the working time of the shift. That is, the degree of dust hazard per shift is:

$$C_n = \frac{13.6 \cdot 0.874}{2} = 5.94. \tag{2}$$

Table 1.
Estimation of working conditions for stone blocks and slabs crushing worker

Factors of the production environment and labour process	Regulatory value (maximum permissible level)	Actual value	Duration, % per shift
Dust, mg/m^3	2	13.6	87.4
Vibration, dB	112	116	100
Noise, dBA	80	91	100

As a result of the calculations carried out according to the formula (2) and using the data in Table 1, the value of the degrees of harmfulness of the factors of the production environment for the change for the path of the plates and blocks was obtained; the results of the calculations are presented in Table 2.

Table 2.
The harmfulness degree of the working environment factors per shift for stone blocks and slabs crushing worker

Factor of production environment and labour process	The harmfulness degree of the working environment factors per shift
Dust	5.94
Vibration	1.04
Noise	1.14

The study results of working conditions in the mining industry show that the development of opencast mineral deposits is associated with excessive levels of production factors that negatively affect overall health, working conditions and productivity (harmful working conditions). The leading place among the harmful factors of the production environment is occupied by dust, noise and vibration, which accompany all technological processes in the quarries from mining, mining to processing and transportation.

3. Results and discussion

3.1. Critical analysis of existing approaches to assessing industrial risk

In today's conditions, the most effective approaches to substantiate the operational planning of measures to reduce occupational risk are approaches based on the use of a priori analysis to assess the state of various factors that generally affect safety and working conditions [5,14,15]. Based on the factors determined as a result of the a priori analysis, mathematical (economic and mathematical) models are constructed. Based on the simulation results, a plan of operational measures for labour protection is formed. When planning measures on the basis of the calculated indicator of occupational risk, first of all, those are selected that give the greatest socio-economic effect at the lowest cost [5]. It has been repeatedly noted that traditional approaches that were used to justify OSH measures cannot be effective if they focus solely on statistical analysis of retrospective data [16,17].

At the same time, despite the abundance of theoretical developments on the application of the risk-based approach, the problems of their practical implementation should be noted.

First, the simpler the proposed approach (or method), the less specific the results of its application and the less effective will be the recommendations for planning measures based on the results obtained.

Secondly, the development, implementation and further effective use of a new approach requires, as experience convincingly shows, scientific and methodological support of all stages of work – from data collection, processing, analysis of the results obtained and ending with the preparation of analytical materials necessary for use in the process planning of measures.

Thirdly, even the effective use of any innovation during a certain period does not yet guarantee its effectiveness for the next planning period, since any changes in the organization of work, technological processes, raw materials used, even personnel changes in personnel – all these factors can lead to an insufficient level the result obtained.

Fourth, in the overwhelming majority of cases, the implementation of the best (or one of the best) option may be impossible due to a lack of the necessary financial resources or other resources, including due to the limited time frame for completing the work.

Fifth, the analysis of the results of the implementation of systems based on the use of a risk-based approach shows that their effectiveness depends on the availability of two components of the system: reliable and updated data in the required volume and a complete nomenclature, as well as on the competence of the experts involved. The absence (or insufficient level) of at least one of these components becomes a real obstacle to improving the efficiency of planning activities.

The results of the analysis of scientific works and publications allow us to conclude that the assessment of occupational risks involves taking into account the characteristics of various types of economic activity, and also requires taking into account and analyzing the existing harmful production factors, technological processes and production equipment, as well as developing an approach (method) that is maximum acceptable for the conditions of a specific production, taking into account the complex accounting of data on factors affecting occupational risk.

3.2. Mathematical model

The mathematical model of the change in dust concentration over a one-hour cycle has the form:

$$Z_i = 0.836 \cdot t - 0.027 \cdot t^2 + 0.00022 \cdot t^3. \quad (3)$$

The correlation coefficient of the model is 0.99, which indicates the high accuracy of the model.

A graphical representation of the obtained mathematical model describing the excess of dust concentration over the maximum allowable level during the operation of the plate and block paths within a one-hour technological cycle is presented in Figure 1.

It is established that the time of exceeding the dust concentration above the maximum allowable level for a one-hour cycle is 40 minutes (starting from the 4th minute).

The average value of the dust concentration per one-hour cycle is calculated by the formula:

$$\overline{Z}_i = \frac{1}{40}\int_4^{44}(0.836 \cdot t - 0.027 \cdot t^2 + 0.00022 \cdot t^3)dt \quad (4)$$

Integrating expression (4) we obtained the average value of the degree of influence of the dust concentration for one hour cycle:

$$\overline{Z}_i = \begin{pmatrix} 0.418 \cdot (44^2 - 4^2) - 0.009 \cdot (44^3 - 4^3) + \\ +0.000055 \cdot (44^4 - 4^4) \end{pmatrix} /40 = 6.13. \quad (5)$$

The degree of harmfulness of the dust concentration per shift:

$$C_n = \frac{1}{2} \cdot \frac{\sum_1^8 \overline{Z}_i \cdot t_i}{T} = \frac{1}{2} \cdot \frac{8 \cdot 6.13 \cdot 40}{480} = 2.05, \quad (6)$$

where T = 480 – shift' duration, min.

Consequently, when implementing the proposed operating mode of the path of the slabs, the time spent in dusty conditions is reduced to 320 minutes per shift, which is 66.7% of the working time (instead of 84.7% - see Table 1, therefore, the time reduction is 84.7-66.7 = 18%). The dust hazard level after changing the operating mode is 2.05 (instead of 5.94, see Table 2).

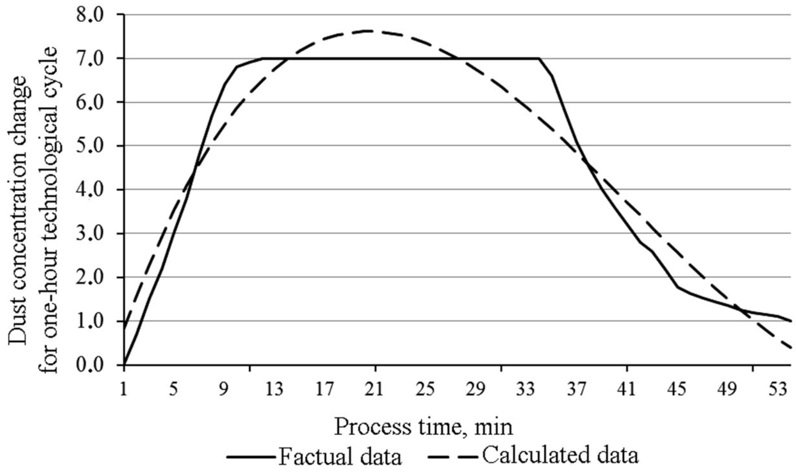

Fig. 1. Mathematical model of dust concentration change for one-hour technological cycle for stone blocks and slabs crushing worker

Similarly, mathematical models for other harmful factors (noise, vibration) were obtained and investigated. The results also made it possible to reduce the harmful effect of production factors on workers, to reduce the level of occupational risk.

3.3. Ways to solve problems

The study of harmful production factors involves, first of all, the preparation of initial data: measurements, entry and processing of results, calculations and further analysis. The next stage involves the construction and study of mathematical models. Moreover, the possibility of identifying more problematic areas is achieved by analyzing the initial data, including comparing actual data and the maximum permissible levels of production factors, and establishing the facts of their exceeding, then the effectiveness of the introduction of corrective actions (measures) can be evaluated only based on the results of mathematical modelling.

If we talk about the proposed approach, then its undoubted advantage is the simplicity and clarity of computational procedures in the process of constructing mathematical models (see formula (1)), therefore, its implementation does not require a specialized computational system, and it is possible to use MS Excel. At the same time, if in the future this approach is considered as an integral part of the enterprise labour protection management system, then for implementation at enterprises it is required to create a specialized information and analytical system, taking into account modern security requirements for embedded and applied software [22]. The use of this system will increase the accuracy of modelling; the visibility of the results obtained, and will also reduce the execution time of all operations related to data processing.

4. Conclusions

The results indicate that the assessment of occupational risks involves taking into account the characteristics of enterprises of different types of economic activity, requires taking into account and analyzing the available data on harmful production factors. The proposed approach, according to the authors, is acceptable for the conditions of the enterprise for the extraction of granite. A feature of which is a comprehensive accounting of data on factors affecting occupational risk, the construction of mathematical models and the use of modelling results when planning measures to improve working conditions. As one of the results of practical application, it should be noted a decrease in the concentration of dust due to reasonable changes in the operating mode of the equipment and rational planning of working hours.

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