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Mathematical modelling of professional risk at Ukrainian metallurgical industry enterprises

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ABSTRACT

Purpose: To develop a more advanced methodology, the application of which will provide an informational and computational and analytical basis for planning and implementing effective preventive measures aimed at minimizing occupational risks with limited resources, as well as in the absence of organizational and technical capabilities to create absolutely safe working conditions.

Design/methodology/approach: For the study, statistical data were used that obtained from enterprises of the metallurgical industry of Ukraine. Research methods: analysis and generalization of known scientific results, methods of statistical analysis, mathematical modelling, expert assessments and decision theory.

Findings: The results of experimental studies have confirmed the possibility of an objective assessment of various options for the OSH management strategy, which allows justifying the allocation of funds for OSH in the required amounts. It is shown that professional risk management strategies are characterized by different efficiency in the use of available financial resources, and the most effective strategy is one that allows you to minimize the level of risk (in comparison with other strategies) with the same amount of funding.

Research limitations/implications: The study focuses on enterprises of the metallurgical industry in Ukraine.

Practical implications: The application of the developed mathematical models demonstrates the effectiveness of financing certain preventive and protective measures, and stimulates the head to ensure industrial safety.

Originality/value: The developed mathematical models allow justifying the allocation of funds for OSH in the required amounts.

Keywords: Industrial risk, Preventive and protective measures, Planning, Mathematical modelling

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INDUSTRIAL MANAGEMENT AND ORGANISATION

1. Introduction

Metallurgical industry enterprises are classified as high-risk enterprises because of the many harmful and dangerous factors affecting workers during the work shift [1-4]. The processes of Ukraine's integration into the international community necessitate the use of new approaches to the organization of labour protection management, focused on international standards. Reforming the state economy requires all participants in the labour protection management process to respond promptly to changes caused by the development of market relations in Ukraine, which, in turn, necessitates improving labour protection management methods. This means that traditional management methods, which were successfully applied in the past, as well as the management experience accumulated by specialists and managers, in today's conditions cannot always be used effectively.

Labour conditions and safety at enterprises are formed under the influence of a large number of factors [5-8]; therefore, industrial injuries and occupational morbidity are the most significant phenomena in production, which cause occupational risk at enterprises of any type of economic activity. In addition, industrial injuries and occupational morbidity remain the most significant indicators by which the effectiveness of OSH management is assessed. At the same time, these negative phenomena (first of all, industrial injuries) can be realized due to an unforeseen coincidence of circumstances or unfavourable development of events, that is, regardless of objective and subjective reasons.

So, the methods of occupational safety management, based solely on the analysis of the causes and circumstances leading to industrial injuries and occupational diseases, do not provide for the priority of preventive measures for occupational safety and health. In addition, the current legislation does not sufficiently stimulate employers to apply the latest methods of labour protection management.

Consequently, the current urgent task is to develop a methodology for substantiating preventive (prophylactic, preventive) measures and means for labour protection, taking into account occupational risk [9-11]. The essence of this problem lies in the fact that the existing approaches to assessing the state of labour conditions and safety are based on indicators of injuries, characteristics of compliance of equipment, technologies, buildings and structures with regulatory requirements [12,13], of which it is impossible to directly determine the list and types of measures by calculation that will provide the greatest risk impact.

Recently, the regulatory and legislative framework of Ukraine on labour protection is increasingly focused on international legislation. The Concept of reforming the OSH management system in Ukraine [14], approved by the Cabinet of Ministers of Ukraine, is aimed at the active use of a risk-based approach [15]. At the same time, as has been repeatedly noted in scientific publications [16-18], for the transition to the methodology of OSH management based on the risk-based approach, fundamentally different theoretical and methodological approaches are needed than those that have been used so far.

According to the results of the analysis of scientific works and publications devoted to the problem of mathematical modelling of indicators of the state of labour safety, the following was revealed:

1. Application of methods of statistical data processing, primarily regression and correlation analysis, for calculating mathematical models of the dependence of indicators of the state of labour protection on a variety of factors [19,20].
2. In the overwhelming majority of cases, the assessment of occupational risks involves taking into account the

characteristics of various sectors of the economy, accounting and analysis of existing harmful production factors, technological processes and production equipment [21-23].

Therefore, the purpose of this work is to develop a more advanced methodology, the application of which will provide an informational and computational and analytical basis for planning and implementing effective preventive measures aimed at minimizing occupational risks with limited resources, as well as in the absence of organizational and technical capabilities to create absolutely safe working conditions.

2. Materials and methods

For the study, statistical data were used (on working conditions at workplaces, on the circumstances of accidents and traumatic situations, on the state of equipment safety, etc.) obtained from enterprises of the metallurgical industry of Ukraine. Research methods: analysis and generalization of known scientific results, methods of statistical analysis, mathematical modelling, expert assessments and decision theory.

In its most general form, a mathematical model that establishes the dependence of the indicator on a variety of factors characterizing the state of labour protection has the form of a polynomial:

$$Y = F(X) = a_0 + \sum_{i=1}^{n} a_i X_i + \sum_{i=1}^{n}\sum_{j=1}^{n} a_{ij} X_i X_j + \dots, \quad (1)$$

where Y – initial variable (the professional risk level); Xi, X_j – input variables (factors); a_0, a_i, a_{ij} – constant coefficients of the model; n – the number of factors taken into account.

The choice of many factors depends on the conditions of a specific problem and the availability of the necessary sets of statistical data. Let us introduce into consideration the function $F_i(X)$, which establishes the dependence of the dynamics of the indicator on the change in the values of i-th factor. In practice, this function characterizes the situation when the implementation of preventive measures (allocation of funds) is carried out exclusively to eliminate (reduce) the impact of i-th factor. In this case, the all other factors' values affecting occupational risk are taken as averages over the array of statistical data:

$$F_i(X) = F(X_i) + F\left(\overline{X}_{j\neq i}\right) \quad (2)$$

where $F(X_i)$ – a mathematical model obtained from formula (1) by setting zero coefficients for all variables except for Xi; $F\left(\overline{X}_{j\neq i}\right)$ – the constant calculated in formula (1) in the case of assigning mean values to all variables with the exception of Xi, as well as excluding the free term a0.

According to the results of the studies carried out on the basis of data obtained at several enterprises of the metallurgical industry of Ukraine, it was found that despite the difference in equipment, technological processes, working conditions, etc., certain patterns of professional risk assessment were obtained. These patterns made it possible to systematize and study the main trends and patterns of changes in the level of professional risk due to the implementation of various management strategies. Management strategy (in this study) refers to the development and planning of OSH measures, their financing, implementation and evaluation of results. Reducing the level of professional risk is taken as the main result of each strategy. That is, the strategy provides for the implementation of the main stages of professional risk management.

To bring the various factors values to a single scale, it is proposed to use the following approach for data pre-processing:

$$X_i' = \frac{X_i - X_i^{min}}{X_i^{max} - X_i^{min}} \cdot 100 \quad (3)$$

where X_i^{max}, X_i^{min} – respectively, the maximum and minimum actual values of the factor X_i, X_i' – normalized factor value $X_i' \in [0;100]$.

In a similar way, you can go to the use of standard values of all investigated factors and indicators. At the same time, the minimum value of each factor will correspond to its minimum impact on occupational risk (minimum harm), and the maximum value (in our case – 100) – the maximum impact.

It is well known that an increase in funding for activities aimed at improving working conditions and ensuring production safety can reduce the level of occupational risk.

The study of the occupational risk management strategy (as a function of the only factor - the amount of funding for labour protection measures) is presented in Figure 1.

Even a visual analysis of the dependences obtained (see Fig. 1) allows us to draw preliminary conclusions that with the same amount of funding for labour protection measures, it is possible to achieve different levels of occupational risk. The main reason for this situation can be considered insufficiently substantiated planning of activities, and, as a consequence, irrational spending of financial resources.

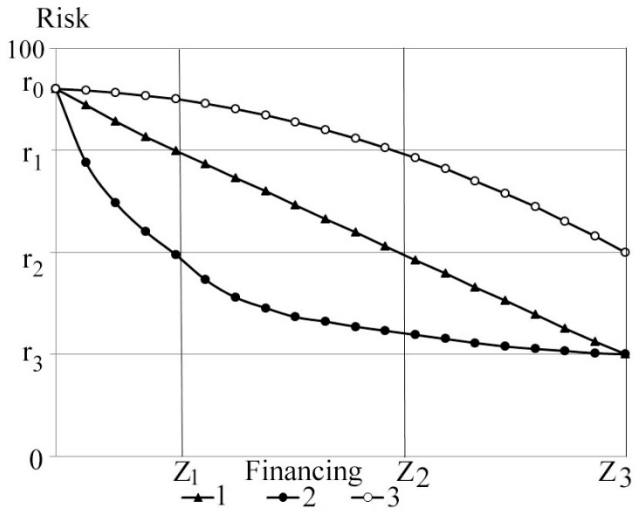

Fig. 1. Research of professional risk management strategies: 1 – professional risk management strategy, which is characterized by the average efficiency of the use of financial resources; 2 – professional risk management strategy, which is characterized by high efficiency in the use of financial resources; 3 – professional risk management strategy, which is characterized by low efficiency in the use of financial resources; r_0 – the maximum value of professional risk, which is fixed before the start of the implementation of activities; r_1, r_2, r_3 – the value of professional risk, which should be achieved subject to financing, respectively, in the amount of Z_1, Z_2, Z_3, when implementing a strategy with an average efficiency in the use of financial resources

3. Results and discussion

Construction of mathematical models that establish the dependence of occupational risk on the amount of funding for labour protection measures carried out using the method of regression-correlation analysis (for three options for the management strategy):

$$\begin{aligned} F_1(Z) &= 93.4107\text{-}3.8538\cdot Z\text{+}0.0433\cdot Z^2\text{-}0.0011\cdot Z^3 \\ F_2(Z) &= 98.4589\text{-}14.2019\cdot Z\text{+}0.9874\cdot Z^2\text{-}0.0234\cdot Z^3 \\ F_3(Z) &= 90.0734\text{-}0.0238\cdot Z\text{-}0.0978\cdot Z^2\text{-}0.0001\cdot Z^3, \end{aligned} \quad (4)$$

where $F_1(Z)$, $F_2(Z)$, $F_3(Z)$ – mathematical models that establish strategies for managing professional risk, respectively – average, maximum and minimum efficiency.

The analysis of the constructed mathematical models, obtained by processing statistical data at enterprises, made it possible to establish some features inherent in all the considered models.

First, all models have the form of decreasing functions. This means that with an increase in funding for labour protection measures (as a result, an increase in the level of safety of equipment and technological processes, normalization of working conditions), the level of occupational risk decreases.

Second, there is a certain minimum (in the general case, not zero) value of the modelled indicator, which is due to the presence of an intercept (a_0) in model (1).

Thirdly, the approximation error of the constructed models does not exceed 2%; the models are a third-order polynomial.

Fourth, despite the similar appearance, none of the obtained models can be used for another data set obtained at any other enterprise.

What opportunities does the manager responsible for professional risk management at the enterprise have if there is information and analytical support; in particular, the obtained mathematical models (see (4))? First of all, it becomes possible to quantify in advance how effective (from the point of view of reducing occupational risk) the financing of a particular labour protection plan can be. In particular, it is possible to establish the amount of funding that must be allocated to reduce the level of professional risk, for example, from r_0 to r_1, and determine (through the corresponding indicator) the efficiency of investment:

$$E = \frac{r_0 - r_1}{Z_1}, \quad (5)$$

where E – indicator of the effectiveness of financing measures for labour protection.

In the general case, the strategy can be considered effective if the inequality $E \geq 1$ is satisfied, since this indicates an excess of the conditional effectiveness of the implementation of labour protection action plans over the conditional amount of their funding.

Using the obtained mathematical relationships (4), it is possible to evaluate the efficiency of financing measures for labour protection for each of the considered management strategies by substituting the corresponding values in formula (5). The result is:

$$\begin{aligned} E &= \frac{90 - 74.9}{25} = 0.604, \\ E &= \frac{90 - 49.5}{25} = 1.624, \\ E &= \frac{90 - 87.5}{25} = 0.10, \end{aligned} \quad (6)$$

Thus, it becomes obvious that management strategies 2 are more attractive to implement in comparison with strategies 1 and 3.

In addition, the results of mathematical modelling stimulate the employer to allocate funds for labour protection, and performers - to actively search for reasonable options for labour protection measures. Also, an objective comparison of the expected results of the implementation of alternative options for the action plan will help attract external investment and improve the company's image.

So, professional risk management strategies are characterized by different efficiency in the use of available financial resources. The most effective strategy is one that allows you to minimize the level of risk as compared to other strategies with the same amount of funding. The issue of efficiency (effectiveness) of risk management requires experimental research by implementing the stages of the developed algorithm. At the same time, the level of professional risk is calculated for professions characterized by the impact of harmful and hazardous production factors; therefore, they need to develop measures to reduce it.

Ways to solve the problem

Despite the advantages of the transition to OSH management based on the construction and study of mathematical models that establish the dependences of many occupational risk factors, it should be noted that there are also disadvantages of this approach associated with its practical implementation:

- first of all, there should be a need for systematic monitoring of working conditions at the enterprise, as well as accounting for the implementation of labour protection measures and the amount of their financing;
- strict recording and evaluation of the results of the implementation of activities must be ensured;
- in some cases, it is necessary to conduct a survey (questionnaire) of employees, for the normalization of working conditions of which appropriate measures were implemented;
- to record such data, special unified forms should be developed that will allow the collected data to be transferred for further processing.

Approbation of the proposed approach was carried out using MS Excel, but for implementation at enterprises, it is expedient and more convenient to use a specialized information and analytical system. The specified system should provide input of initial data and further formation of the database, calculation of model coefficients, visualization of simulation results, and the like. Therefore, in any implementation of the proposed approach, it is necessary to train personnel with a demonstration of the main stages of data preparation, calculations, obtaining and using the results.

4. Conclusions

To improve the management of labour protection at enterprises, the use of a risk-based approach is proposed. An approach to assessing professional risks is proposed, a feature of which is the use of the results of mathematical modelling. This approach is essentially the basis of information and analytical support for planning activities aimed at reducing professional risk.

The results of experimental studies have confirmed the possibility of an objective assessment of various options for the OSH management strategy, which allows justifying the allocation of funds for OSH in the required amounts. It is shown that professional risk management strategies are characterized by different efficiency in the use of available financial resources, and the most effective strategy is one that allows you to minimize the level of risk (in comparison with other strategies) with the same amount of funding.

The application of the approach proposed by the authors helps to stimulate employers to ensure safe and harmless working conditions, and also provides for the active involvement of workers in participating in solving labour protection problems.

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Additional information

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References

[1] T. Małysa, K. Nowacki, T. Lis, The correlation between structure of employment and accidents at work in metallurgical enterprises, Proceedings of the 26th International Conference on Metallurgy and Materials “METAL’2017”, Brno, Czech Republic, 2017, 2244-2249.

[2] S. Ragimov, V. Sobyna, S. Vambol, V. Vambol, A. Zakora, E. Strejekurov, V. Shalomov, Physical

modelling of changes in the energy impact on a worker taking into account high-temperature radiation, Journal of Achievements in Materials and Manufacturing Engineering 91/1 (2018) 27-33.
DOI: https://doi.org/10.5604/01.3001.0012.9654

[3] N. Mozaffari, N. Mozaffari, S.M. Elahi, S. Vambol, V. Vambol, N.A. Khan, N. Khan, Kinetics study of CO molecules adsorption on Al_2O_3/Zeolite composite films prepared by roll-coating method, Surface Engineering 37/3 (2020) 390-399.
DOI: https://doi.org/10.1080/02670844.2020.1768628

[4] L. Wuxuan, W. Zhimin, Application of numeric simulation for assessment & pre-warning of industrial dangerous source, China Safety Science Journal 2 (1995).

[5] N.A. Khan, G.R. Sinha, S. Ahmed, A. Feshchenko, F. Changani, A. Qureshi, M.A. Mazhar, I. Neklonskyi, Collection of hospital wastewater data using deduplication approaches, Archives of Materials Science and Engineering 104/1 (2020) 5-18. DOI: https://doi.org/10.5604/01.3001.0014.3864

[6] D. Sokolov, V. Sobyna, S. Vambol, V. Vambol, Substantiation of the choice of the cutter material and method of its hardening, working under the action of friction and cyclic loading, Archives of Materials Science and Engineering 94/2 (2018) 49-54. DOI: https://doi.org/10.5604/01.3001.0012.8658

[7] O. Popov, A. Iatsyshyn, D. Sokolov, M. Dement, I. Neklonskyi, A. Yelizarov, Application of Virtual and Augmented Reality at Nuclear Power Plants, in: A. Zaporozhets, V. Artemchuk (eds.), Systems, Decision and Control in Energy II. Studies in Systems, Decision and Control, vol. 346, Springer, Cham, 2021, 243-260. DOI: https://doi.org/10.1007/978-3-030-69189-9_14

[8] S. Vambol, V. Vambol, K.A.H. Al-Khalidy, Experimental study of the effectiveness of water-air suspension to prevent an explosion, Journal of Physics: Conference Series 1294/7 (2019) 072009. DOI: https://doi.org/10.1088/1742-6596/1294/7/072009

[9] V. Golinko, S. Cheberyachko, O. Deryugin, O. Tretyak, O. Dusmatova, Assessment of the risks of occupational diseases of the passenger bus drivers, Safety and Health at Work 11/4 (2020) 543-549. DOI: https://doi.org/10.1016/j.shaw.2020.07.005

[10] S.I. Cheberiachko, V.V. Hilpert, Y.I. Cheberiachko, I.A. Shaikhlislamova, A.N. Borovitsky, Formation of enterprise employees' risk-oriented thinking of safe work, Labour Protection Problems in Ukraine 37/1 (2021) 9-15.
DOI: https://doi.org/10.36804/nndipbop.37-1.2021.9-15

[11] R.I. Moraru, A.P. Păun, C.C. Dura, R. Dinulescu, A.M. Potcovaru, Analysis of the drivers of occupational health and safety performance disclosures by Romanian companies, Economic Computation and Economic Cybernetics Studies and Research 54/3 (2020) 197-214.
DOI: https://doi.org/10.24818/18423264/54.3.20.12

[12] V. Glyva, S. Podkopaev, L. Levchenko, O. Khodakovskyy, B. Khalmuradov, Design and study of protective properties of electromagnetic screens based on iron ore dust, Eastern-European Journal of Enterprise Technologies 1/5(91) (2018) 10-17. DOI: https://doi.org/10.15587/1729-4061.2018.123622

[13] O. Kruzhilko, O. Polukarov, S. Vambol, V. Vambol, N.A. Khan, V. Maystrenko, V.P. Kalinchyk, A.H. Khan, Control of the workplace environment by physical factors and SMART monitoring, Archives of Materials Science and Engineering 103/1 (2020) 18-29. DOI: https://doi.org/10.5604/01.3001.0014.1770

[14] On approval of the Concept of reforming the labour protection management system in Ukraine and approval of the action plan for its implementation, Cabinet of ministers of Ukraine order dated December 12, 2018, № 989-r, Kyiv (in Ukrainian). Available from: https://zakon.rada.gov.ua/laws/show/989-2018-%D1%80?lang=ru#Text

[15] O. Kruzhilko, V. Maystrenko, O. Polukarov, V.P. Kalinchyk, A. Shulha, A. Vasyliev, D. Kondratov, Improvement of the approach to hazard identification and industrial risk management, taking into account the requirements of current legal and regulatory acts, Archives of Materials Science and Engineering 105/2 (2020) 65-79.
DOI: https://doi.org/10.5604/01.3001.0014.5763

[16] I.L. Nunes, Occupational safety and health risk assessment methodologies, OSH Wiki networking knowledge, EU-OSHA—European Agency for Safety and Health at Work, 2013. Available from: https://oshwiki.eu/wiki/Occupational_safety_and_health_risk_assessment_methodologies

[17] T. Kaverzneva, N. Rumyantseva, A. Uljanov, N. Belina, Use of the logical-statistical model as a procedure for assessing occupational risks in the OSH management, IOP Conference Series: Materials Science and Engineering 666/1 (2019) 012091. DOI: https://doi.org/10.1088/1757-899X/666/1/012091

[18] O. Kruzhilko, V. Maystrenko, V. Kalinchyk, Y. Polukarov, L. Mitiuk, N. Bilotserkivska, L. Borysova, T. Kachur, Development of the effective information and analytical support of the OSH management system, Journal of Achievements in Materials and

Manufacturing Engineering 99/2 (2020) 72-84. DOI: https://doi/org/10.5604/01.3001.0014.1777

[19] O. Kruzhilko, R. Cherneha, V. Maystrenko, O. Polukarov, V. Kalinchyk, Modelling and forecasting the workplace environmental physical factors values, Archives of Materials Science and Engineering 100/1-2 (2019) 21-33. DOI: https://doi/org/10.5604/01.3001.0013.5999

[20] O. Terentiev, K. Tkachuk, O. Tverda, A. Kleshchov, Mathematical model of the reverse water post purification at mining enterprises when using electromagnetic focusing of contaminants, Eastern-European Journal of Enterprise Technologies 1/10(91) (2018) 11-16. DOI: https://doi.org/10.15587/1729-4061.2018.122000

[21] I. Iordanov, Y. Simonova, O. Kayun, Y. Podkopayev, A. Polozhii, H. Boichenko, Substantiation of the stability of haulage drifts with protective structures of different rigidity, Eastern-European Journal of Enterprise Technologies 3/7(105) (2020) 87-96. DOI: https://doi.org/10.15587/1729-4061.2020.202483

[22] I. Iordanov, Y. Novikova, Y. Simonova, O. Yefremov, Y. Podkopayev, A. Korol, Experimental characteristics for deformation properties of backfill mass, Mining of Mineral Deposits 14/3 (2020) 119-127. DOI: https://doi.org/10.33271/mining14.03.119

[23] S.A. Sukach, T.A. Kozlovskaya, I.A. Serhiienko, V.B. Glyva, O.C. Vovna, I.C. Laktionov, Research and formation of qualitative hydro air ion composition in agricultural premises, Bulgarian Journal of Agricultural Science 25/2 (2019) 256-263.