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European Journal of Advances in Engineering and Technology, 2020, 7(10):26-32

Research Article ISSN: 2394 - 658X

Methodology for Determining Potential Industrial Risks on the Basis of Mutual Influence of Harmful Factors of the Industrial Environment and Labour Process

Tretyakov Oleg, Harmash Bohdan and Yevheniia Biletska

Department of Human Engineering and Enviromental Protection,
Ukrainian State University of Railway Transpo, Kharkiv, Ukraine

ABSTRACT

The article deals with the issues of methodological support, which is used in the certification of workplaces to determine the level of danger of workers in their work area. Theoretical basis for the formation of the concept of safety in the organizational and technical systems was chosen Weber-Fechner law: it is established the presence of the threshold of feeling, it means that there is a possibility of mathematical calculation of levels of exposure to factors of the working environment and the work process with subsequent determination of the harmfulness of the industrial process as a whole. It is proposed to determine the level of danger in the working area using the risk function, which will automate the process of certification of workplaces. The risk dependencies for the environment quality parameters - industrial factors included in the list of hazardous and harmful industrial factors - have been determined for the subsequent calculation of potential risk taking into account the simultaneous impact of heterogeneous factors on the workers. A mathematical model for determination of integral risk on the basis of an algorithm for transformation of environment parameters into an index of industrial risk, which takes into account the joint action of harmful factors of different nature, has been developed. With the help of the developed model of integral risk determination, a quantitative assessment of potential harmfulness of industrial processes for the workers of welding department of the locomotive depot was made. According to the results of the conducted assessment, the mutual strengthening of harmful influence of factors of industrial environment and working process for a number of located workplaces was established.

Key words: occupational risk, industrial risk, hazardous factor, occupational safety and health, hygiene standard

INTRODUCTION

The modern society now occupies such position that each person is self-priced and unique, and his health is the main wealth of any state. The World Health Organization has defined the parametrical characteristics of health as "objective state and subjective feeling of full physical, psychological and social comfort, and not only absence of diseases" [1]. The Global Fatal Accident Assessment conducted by the International Labour Organization (ILO) shows that more than 300,000 people die at work each year worldwide [2]. The World Congress on Occupational Safety and Health presented data on annual mortality from "work-related diseases" in the world: it is 2.2 million people. Thus, in 15 countries of the European Union they account for 120,000 deaths, which is 20 times more than the number of accidents at work [3]. Therefore, the concept of "work-related illnesses" is broader than that of "occupational illnesses", which includes all diseases caused by work.

Occupational diseases have clear links with the nature of the work performed. Diseases provoked by harmful working conditions have an incredibly long incubation period, resulting in various forms that are not always easy to recognize. Many years of research by scientists in many countries of the world show that up to 30% of the consequences of health deviations are caused by harmful and dangerous factors that are generated in the industrial environment [3]. Systematic influence of harmful industrial factors of different nature in the process of work causes hidden damage to the body, awareness of which comes when there are clear signs of disease and when it is no longer possible to correct the situation by preventive measures. With this in mind, the conceptual position of occupational safety, which reflects the ILO global strategy "Decent Work must be safe", is formulated as follows: "A productive activity in which an individual is exposed to excessive risk cannot be justified, even if it is beneficial to society as a whole" [4]. Ukraine has undertaken to bring its national legislation in line with EU legislation. This means that for integration into the world community it is necessary to develop and implement the basic provisions in the field of occupational safety and health of workers, to harmonize its own principles, methods and criteria for assessing the health risk to workers in working conditions with international approaches [5].

For formation of the new concept of safety in organizational and technical systems the Weber-Fechner law can be chosen as a theoretical basis [6].

The purpose of the research is to develop methodological support for determining the level of danger for employees in their working area taking into account the joint action of harmful factors of different nature on the basis of the integral index - industrial risk.

RESEARCH RESULTS

Risk assessment involves considering at least two types of risk: real and potential. The real risk is the quantitative expression of health damage in the amount of illness or death. Potential risk is a risk of occurrence of an adverse effect for a person, which is defined as a probability of occurrence of this effect under given conditions. It can be expressed in percents, fractions of a unit or in cases per 1000, 10000 [6]. But there is a need to scientifically put into practice the requirement of the well-known ALARA principle: the risk level should be as low as possible in these economic and social conditions [7].

Probabilistic methods represent results as distributions of probabilities or as limits of distributions. They can also produce results when most distributions or distribution limits fall below a safe threshold. There are many uncertainties in risk estimates that are ignored because it is not so easy to incorporate them into analysis. The reason may be a lack of proper methodology, which has not yet been developed, or there is often a lack of information to select a distribution [8].

For a probabilistic assessment, it is necessary to determine the amount of acceptable risk or the magnitude of acceptable safety, but in the real world it is necessary to consider the measurement error in the safety assessment. On the other hand, the estimation procedure becomes more complicated, as it is possible that the true value may be at any point in the area of change of the measured parameter [9].

ДСТУ ISO 31000: 2018 defines risk assessment as a process consisting of three stages: risk identification, risk analysis and risk assessment [10]. The object of danger is any part of the "man-machine- environment" system. This combination of circumstances becomes possible provided that there are certain vulnerable links in the system. In this case we mean factors of industrial risk which promote realization of risk in concrete professional danger directly at interaction of object of risk with object of danger.

It is known that a hazard object always exists when there is a risk object. Since the object of risk in the field of labor protection is a person, therefore, these conditions are constant. Since the variables in statistics are probabilities, the form of expression of theoretical risk is a statistical indicator, which is reduced to the probability of occurrence of some undesirable event. The probability of such an event, some estimate of the expected harm, is combined into one indicator, and therefore a set of risk probabilities and the appearance of harm or reward are combined. Risk function $\boldsymbol{\delta(x)}$ for the parameter $\boldsymbol{\theta}$, that calculated at some observed parameters $\boldsymbol{x}$ in statistical theory of decision-making is defined as a mathematical expectation of the loss function $\boldsymbol{L(\theta, \delta(x))}$:

$$R(\theta) = \int L(\theta, \delta(x)) \cdot f(x \mid \theta) dx, \tag{1}$$

where $L(\theta, \delta(x))$ – loss function from valuation parameter $\boldsymbol{\theta}$ and evaluation value $\boldsymbol{\delta(x)}$;

$f(x \mid \theta)$ – the odds of an adverse event.

Estimates of risk in the working area under the influence of environmental factors are made with the assumption that the level of contamination is known [11]. This means that the pollution event has already occurred.

According to the Weber-Fechner law, in general, in case of air pollution, there is a certain functional dependence between the level of pollution, perception and risk:

$$r = 1/k \cdot \lg C/C_0, \tag{2}$$

where r – the level of risk;

C – the concentration of airborne pollution, mg/m^3;

k – the factor of proportionality;

C_0– the lowest concentration, where the effect is felt.

Based on the normative indicators to be determined experimentally for each individual substance, it is realistic to establish two fixed points of dependence (2). If the replacement is made from ***1/k*** to ***λ*** for ease of change, then the equation will take the following form:

ГДК (permissible exposure limit)

ЛК (lethal concentration)

$$\begin{cases} 1\cdot 10^{-6} = \lambda \cdot \lg \text{ГДК}_{\text{СД}}/\text{C}_0 \\ 0{,}5 = \lambda \cdot \lg \text{ЛК}_{50}/\text{C}_0 \\ \text{r} = \lambda \cdot \lg C/C_0 \,. \end{cases} \quad (3)$$

System of equation solution (3) to determine contaminant concentrations, exceeding $\textbf{\textit{ГДК}}_{сд}$, as a result, it will have the following appearance:

$$r = \left(0{,}5 - 1\cdot 10^{-6}\right) / [\lg (ЛК_{50} / ГДК_{СД})] \cdot \lg\left(\text{С}/\text{ГДК}_{\text{СД}}\right) + 1\cdot 10^{-6}. \quad (4)$$

It is possible to determine the risk relationships for noise levels, ionizing radiation and electromagnetic fluctuation, and to calculate the potential risk taking into account the simultaneous action of different factors by analogy (Table 1).

Table -1 The calculation of the potential risk under the influence of heterogeneous factors

ГДК (permissible exposure limit)

ГДР (alarm level)

ЛК (lethal concentration)

ГДЕЕ (maximum permissible energy load)

Quality environment parameters	**Units of measurement**	**Acceptable level standard**	**Harmful level**	**Formula to calculate the risk**
Chemical substances	mg/m^3	ГДК$_{сд}$, depends on the substance	ЛК$_{50}$	$r = 10^{-6} + b \cdot \lg \frac{C}{ГДК}$
Noise	dBA	ГДР	130 dBA	$r = 10^{-6} + 0{,}038 \cdot \lg \frac{I}{I_0}$
Ionizing radiation	m3 per year^{-1}	Dose limit ГДР=20	>50	$r = 10^{-6} + 0{,}358 \cdot \lg \frac{D_E}{ГДР}$
Electromagnetic fluctuation	W/m^2	ГДЕЕ, depends on frequency	>500	$r = 10^{-6} + k \cdot lg \frac{E}{ГДЕЕ}$

The main action in hazard level assessment will be transformation of information about some property of environment parameters into risk indicators. At this stage, there may be a difficulty associated with the fact that previous studies of the nature of the impact of harmful substances and other factors were conducted without regard to their mutual influence. Therefore, the question of transformation of the "dose-effect" will be solved on the basis of available experimental data in *Table 1*. Thus, the specified transformation can be performed with respect to each elementary property. And the next step is to bring the individual indicators to a single criterion of quality of the system as a whole.

The total risk calculation will proceed in the following sequence. First, the values of the annual risk for each factor $\boldsymbol{r_i}$ are calculated, and then the integral risk value is calculated:

$$R = 1 - \prod_{1=1}^{n} \left(1 - r_i\right), \quad (5)$$

The above shows that a unified approach to calculating the evaluation of parameters of the working zone has been found, which also does not require the introduction of multiple scales to characterize the quality of the environment.

But it is also necessary to take into account the presence of the worker in the zone of influence of the dangerous factor ***i***. It is possible to determine the probability of the presence of the hazardous factor ***i*** in the working area using this formula:

$$P_{v_i} = P_i^v \cdot P_i^p , \tag{6}$$

where P_i^v – the probability of action dangerous factor of ***i***;

P_i^p – the odds of an employee working in the area dangerous factor of ***i***.

Then we determine the probability of action dangerous factor of ***i*** and probability of finding the worker in the area of it`s action according to the formulas:

$$P_i^v = t_i^v / T_{CM} \text{ i } P_i^p = t_i^p / T_{CM} , \tag{7}$$

where t_i^v – the action time dangerous factor of ***i***;

t_i^p – the time of presence of the employee in the coverage area dangerous factor of ***i***;

T_{CM} – the stay period of the change.

The obtained expressions can be substituted by the formula (6), as a result, we have a probability of action dangerous factor of ***i*** on the worker:

$$P_{v_i} = \frac{1}{T_{CM}^2}\left(t_i^v \cdot t_i^p\right). \tag{8}$$

In the case where there are simultaneously 2, 3, … ***n*** harmful factors, the probability of their action can be determined as follows:

$$\begin{aligned} P_v(2) &= P_{v_2} + P_{v_1} - P_{v_2} \cdot P_{v_1} \\ P_v(3) &= P_{v_3} + P_{v_2} - P_{v_3} \cdot P_{v_2} \\ P_v(n) &= P_{v_n} + P_{v_{n-1}} - P_{v_n} \cdot P_{v_{n-1}} \end{aligned} . \tag{9}$$

If the probability of influence of harmful factors on the workers is known, the further determination of harmfulness of the production process as a whole will take place as follows:

$$P_{nn}^0 = \frac{N_1 P_0(1) + N_2 P_0(2) + ... + N_n P_0(n)}{N}, \tag{10}$$

where N_1, N_2, … N_n – the number of workers who are affected 1, 2, 3, … ***n*** harmful factors;

$P_0(1)$, $P_0(2)$, ... $P_0(n)$ – the employability 1, 2, 3, … ***n*** harmful factors;

N – the total employment.

The probability of action is then determined dangerous factor by formula of ***j***:

$$P_{b_j} = P_j^b \cdot P_j^p \cdot P_j^{nc}, \tag{11}$$

де P_j^b – the odds of being in the work area hazardous factor (substance) of ***j***;

P_j^p– the odds of human presence in the area hazardous factor (substance) of ***j***;

P_j^{nc}– the astonishing impact hazardous factor (substance) of ***j***.

As noted above, the probability of having a working area hazardous factor (or substance) of ***j*** and the probability of finding a person in the area of this factor is determined by the formula (7). And the astounding ability hazardous factor (substance) of ***j*** is defined as:

$$P_j^{nc} = \frac{d_j}{D_j}, \tag{12}$$

d_j – the actual level (content) dangerous factor (substance) of ***j***;

D_j – the limit level (content) dangerous factor (substance) of ***j***.

As it is known, borderline level (content) hazardous factor (substance) of ***j*** – is the level at which workers must be quickly evacuated from the danger zone. If you put the formula (11) for P_j^b, P_j^p i P_j^{nc}, then the formula will have the following form:

$$P_{b_j} = \frac{t_j^b \cdot t_j^p \cdot d_j}{T_{CM}^2 \cdot D_j}. \tag{13}$$

Total probability of harmful impact ***m*** factors is determined by the formula:

$$P_b(m) = 1 - \prod_{j=1}^{m}\left(1 - P_{b_j}\right). \quad (14)$$

On the basis of algorithm of environment parameters transformation into industrial risk index the quantitative assessment of potential harmfulness of industrial processes was made on the basis of data on assessment of industrial environment and labor process factors with the use of developed model of integral risk determination for employees with harmful working conditions of crane shop (АФ-1) of "Locomotive Depot Основа" SE "Southern Railway" industrial unit.

The electric welder (WP № 11) in the АФ-1 employs two people, their workplaces are located at a distance of 1.6 meters from each other [12]. Electric welders` workplaces (WP № 11a, WP № 11b) must meet the requirements of these normative documents [13-16]. During work on employees of the welding department the factors which are included into the list of dangerous and harmful industrial factors defined in the Hygienic Classification of work on indicators of harmful and dangerous factors of the industrial environment, severity and intensity of labour process [17], and are characteristic for many kinds of welding and similar processes [18-20].

The results of the assessment of parameters of the working zone of electric welders, which was carried out taking into account the mutual influence of harmful and dangerous factors for these workplaces, are given in [21]. According to the Methodology of calculation of electromagnetic field level distribution [22], the intensity of IR radiation depending on distance was calculated for the working places of the welding department employees taking into account the mutual influence from the workplaces located nearby. *Figure 1* shows a graph of the change of IR radiation intensity at two electric welding` workplaces (WP № 11a and WP № 11b) as a function of distance, taking into account the mutual influence between them. The results of the assessment of parameters of the electric welders` working zone, taking into account the mutual influence of harmful and dangerous factors for their workplaces, are given in [21].

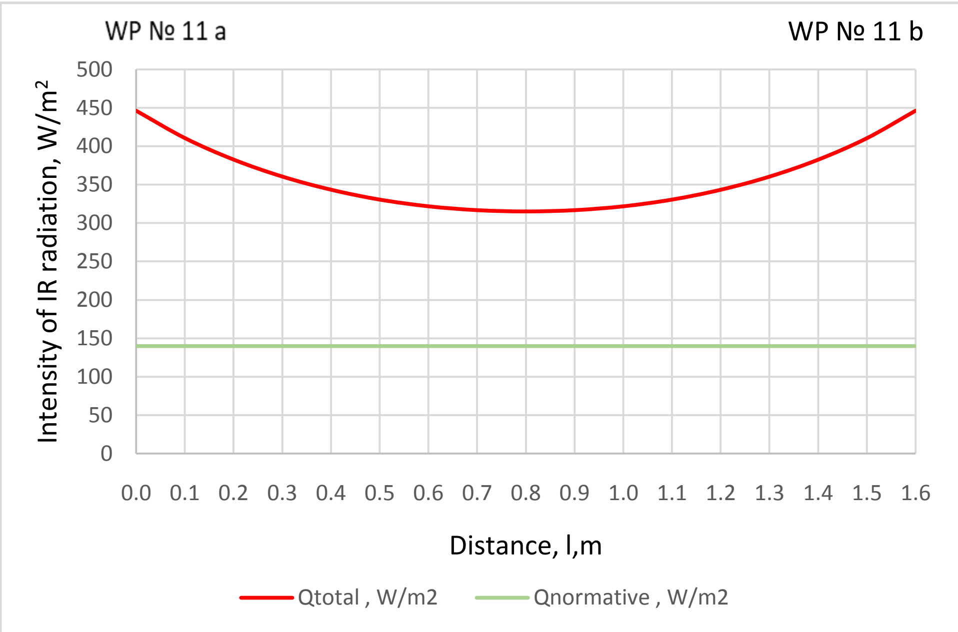

Fig. 1 IR radiation intensity change graph as a function of distance at electric welders` workplaces (WP №11a and WP № 11b)

Mutual influence of harmful factors of industrial environment and labor process for the specified electric welders was estimated by means of industrial risk taking into account mutual influence from intensity of IR radiation. The IR radiation factor was chosen as a harmful factor with an excessive value of potential risk ($\boldsymbol{r_i}$ = 0.156705) [21] according to [23]. The results are given in *Table 2*.

Table -2 Results of calculation of industrial risk index with consideration of mutual influence from IR radiation intensity for welding department workers

Distance between the workplaces, L, m	Intensity of IR radiation, Q_{total}, W/m^2	Integral risk, R_{int}
0.00	446.38	0.193531
0.10	410.79	0.179662
0.20	382.58	0.167790

0.30	360.44	0.157841
0.40	343.41	0.149761
0.50	330.79	0.143512
0.60	322.09	0.139065
0.70	317.00	0.136404
0.80	315.32	0.135518

The received results testify to mutual strengthening of harmful influence of factors of the industrial environment and labour process on electric welders, which workplaces are located nearby. It was determined that the obtained values of potential risk at a distance of 0.8 meters from the electric welders' workplaces are excessive ($\boldsymbol{R_{int}} > 10^{-1}$).

On the basis of the obtained data, a three-dimensional model of the industrial risk zone for the welding department workplaces was constructed (WP № 11a, WP № 11b), which visually represents the picture of the hazard level around the electric welders' workplaces (Figure 2).

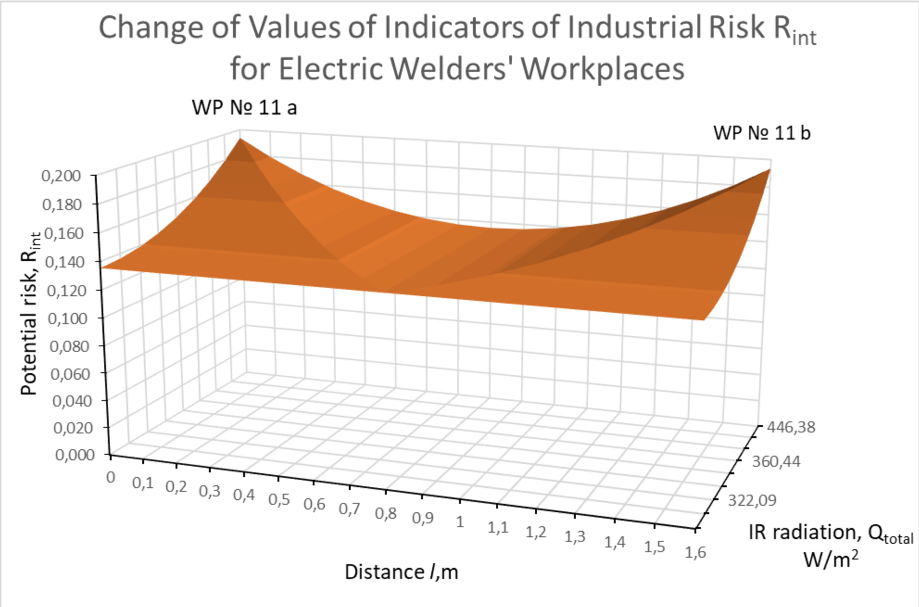

Fig. 2 Industrial risk level due to IR radiation for electric welders' workplaces located nearby (WP №11a and WP № 11b)

Thus, the application of the proposed approach allows to estimate the values of potential industrial risk at any number of harmful and hazardous factors at the workplaces, taking into account their mutual influence, as well as to allocate hazardous zones between workplaces to determine the optimal and most hazardous routes of employees' movement in the workshop.

CONCLUSIONS

The developed methodical support on the basis of the algorithm of transformation of environment parameters into the index of industrial risk for determination of the level of danger of workers in the working zone during certification of workplaces takes into account the joint action of harmful factors of different nature. The quantitative estimation of potential harmfulness of industrial processes with the use of the developed model of determination of integral risk for the workers of welding department has found out mutual strengthening of harmful influence of factors of industrial environment and labour process on workers. Introduction of the integrated harm index will allow to take into account mutual influence, to estimate values of potential industrial risk at any quantity of harmful and dangerous factors at workplaces, and also to allocate dangerous zones between workplaces and to define optimum and most dangerous routes of movement of workers in shop. Such an approach will allow to improve the system of certification of workplaces and increase the reliability of the obtained results of labour conditions assessment.

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