IOSR Journal of Research & Method in Education (IOSR-JRME)
e-ISSN: 2320–7388, p- ISSN: 2320-737x Volume 11, Issue 1 Ser. I (Jan. – Feb. 2021), PP 18-26
www.iosrjournals.org

Methodical Basis Of Risk-Oriented Approach To The Implementation Of Topographic Method Of Industrial Traumatism Forecasting

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Abstact: *The article describes a methodical approach to the use of risk-oriented approach to the implementation of topographic method of forecasting industrial traumatism in modern conditions, the basis of which is the assessment of industrial risks to ensure the management system of occupational health and safety and the cycle of continuous improvement of Shuhart-Deming. Weber-Fechner and S. Stevens' laws were taken as a basis for calculation of occupational and industrial risks depending on the parameters of the working area with consideration of time of stay of the workers in the zone of hazardous factors.*
An algorithm to convert environment parameters into an industrial risk index has been developed. There was an analysis of cards of working conditions based on the results of certification of some workplaces of the regional branch "Southern Railway" PJSC "Ukrainian Railway" taking into account the probability of the hazardous factor, and the probability of staying in the area of its action. The fact that the action of harmful and hazardous industrial factors is not limited to the working area only, but is distributed in the area in accordance with established laws.
Such approach allows to estimate mutual reinforcement of harmful and hazardous factors action in area and to define the most dangerous zones in the crane shop premises. The received results testify to mutual strengthening of harmful influence of factors of industrial environment and labour process on workers of welding and diesel departments. Application of the offered approach allows to estimate values of potential industrial risk at any quantity of harmful and hazardous factors on workplaces, taking into account their mutual influence, to define zones with the largest levels of industrial risk between workplaces and on any distance from them, for definition of optimum and most hazardous routes of movement of workers on the territory of workshop.
Keywords: *occupational risk, industrial risk, harmful factor, hazardous factor, topographic method of forecasting industrial traumatism.*

Date of Submission: 26-12-2020 Date of acceptance: 07-01-2021

I. Introduction

Methods of industrial traumatism analysis are designed to identify the causes and determine the patterns of its occurrence. The use of modern methods of analysis should give an opportunity to objective assessment of traumatism and development of effective measures on its prevention.

Probabilistic and statistical methods of traumatism analysis, which include statistical, group and topographic, allow to reveal the dependence between the factors of the system "man - machine - working area" and traumatism on the basis of the study of accidents that have already occurred [1].

In particular, the topographic method of traumatism analysis is based on the fact that the plan of the workshop (enterprise) marks the places where the accidents occurred, or on the scheme, which is the contours of the human body, where the organs or parts of the body are marked as injured. This makes it possible to clearly see the places with increased danger or the most frequently injured organs. That is, the application of these methods of analysis requires actual data on accidents that have already taken place, and therefore can not be used in the design of new facilities or reconstruction of existing ones, which significantly reduces the possibility of their application.

All the more so because in modern world practice hazardous situations are predicted from the point of view of studying possible risks [2].

The safety criteria should be based on a scientifically grounded theory of occupational and industrial risk, taking into account all theoretical and practical aspects of safe labor, as they not only intersect with many other fundamental areas of scientific research, but are themselves extremely versatile.

Recently, the approaches based on the assessment of industrial risks deserve more and more attention. Above all, these are risk-based occupational health and safety management systems and the cycle of continuous improvement of Shuhart-Deming [3].

In recent years, the topographic method of predicting traumatism has become increasingly important for the assessment of industrial risk in real industrial conditions, as it is aimed at identifying the most dangerous areas in the shop floor and allows you to clearly distinguish the occupational risk of traumatism to the health of an employee from the industrial risk.

Thus, modern requirements of the occupational health and safety management system require revision of the basics of implementation of the topographic method of traumatism analysis and its transfer to the risk-oriented approach.

Study objective: Justification of risk-oriented approach for application of topographic method of industrial traumatism forecasting.

Research results: The existing mathematical models of risk, which are based on methods of probability theory and mathematical statistics, have now acquired quite a large theoretical and practical value because of the need to solve specific problems of analysis of various risk situations from insignificant to catastrophic level, the number of which is constantly growing. [4].

The concept of "occupational risk" in regulatory documents is defined as the amount of probability of violation (damage) of health of an employee, taking into account the severity of consequences as a result of the adverse impact of factors of the working area and the labor process [5]. And hygienic assessment of occupational risk should be carried out taking into account the amount of exposure of these factors, indicators of the employee's health and disability [6].

The analysis of a wide range of scientific publications [7-10] allows to assert that the theoretical basis for the formation of the security concept in organizational and technical systems is the axiom of potential danger, the Weber-Fechner law, the S. Stevens law, the Libich minimum principle, the Shelford tolerance law, the Farmer principle.

Previous studies have determined the dependence of occupational risk on the level of various harmful and hazardous industrial factors, based on the laws of Weber-Fechner and S. Stevens [11, 12] (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	$r = 10^{-6} + k \cdot lg \frac{E}{ГДЕЕ}$

At simultaneous influence of harmful and hazardous industrial factors on the employee the integral risk value is calculated by the formula:

$$R = 1 - \prod_{1=1}^{n} (1 - r_i) \quad (1)$$

The dependencies obtained when used to certify jobs will greatly facilitate the assessment of factors in the working environment and work process.
Based on the algorithm of transformation of environmental parameters into an index of industrial risk, there was an analysis of cards of working conditions based on the results of certification of workplaces of the regional branch "Southern Railway" of PJSC "Ukrainian Railway". The obtained results are given in Table 2.

Table 2 – Estimated values of potential and integral industrial risks for some workplaces

№	*Workplace, profession, workshop (section, department)*	*Class of working conditions*	*Factors of production environment and working process*	*Standard value (ГДК), (ГДР)*	*Actual value*	*Potential risk, r_i,*	*Integral risk, R_{int}*
1	2	3	4	5	6	7	8
1.	Electric welder (engaged in cutting and manual welding)	3.2	Hazardous chemicals, (Manganese)	0,2	0,24	0,009003	0,774952
			Dust of fibrogenic action (iron oxide)	6	6,7	0,008205	
			Infrared radiation, W/m^2	140	358	0,156705	
			Working posture	10	38	0,728481	
2.	Locksmith to repair rolling stock (diesel testing)	3.1	Noise, dBA	80	90	0,001945	0,001945

To take into account the probability of a worker being in the zone of action of the hazardous factor of ***i***, we determine the probability of presence of the hazardous factor of ***i*** in the working zone according to the following formula:

$$P_{v_i} = P_i^v \cdot P_i^p , \quad (2)$$

where P_i^v – the probability of action hazardous factor of ***i***;
P_i^p – the odds of an employee working in the area hazardous factor of ***i***.

The next stage is to determine the probability of action of the hazardous factor of ***i*** and the probability of staying of the worker in the zone of his action respectively:

$$P_i^v = t_i^v / T_{CM} \quad \text{i} \quad P_i^p = t_i^p / T_{CM} \quad , \quad (3)$$

where t_i^v – the action time hazardous factor of ***i***;
t_i^p – the time of presence of the employee in the coverage area hazardous factor of ***i***;
T_{CM} – the stay period of the change.
By substituting the obtained expressions in the formula (2), we get the probability of the hazardous factor of ***i*** action on the worker in the following form:

$$P_{v_i} = \frac{1}{T_{CM}^2} \left(t_i^v \cdot t_i^p \right). \quad (4)$$

Provided that there is a simultaneous presence of 2, 3, ... ***n*** harmful factors, the probability of their action can be determined as follows:

$$\begin{aligned} P_v(2) &= P_{v_2} + P_{v_1} - P_{v_2} \cdot P_{v_1} \\ P_v(3) &= P_{v_3} + P_{v_2} - P_{v_3} \cdot P_{v_2} \\ P_v(n) &= P_{v_n} + P_{v_{n-1}} - P_{v_n} \cdot P_{v_{n-1}} \end{aligned} \quad . \tag{5}$$

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

$$P_{nn}^{0} = \frac{N_1 P_0(1) + N_2 P_0(2) + \ldots + N_n P_0(n)}{N}, \tag{6}$$

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.
Then the probability of action of the hazardous factor of ***j*** is determined by the formula:

$$P_{b_j} = P_j^b \cdot P_j^p \cdot P_j^{nc}, \tag{7}$$

where 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***.

It is established that the probability of presence of the hazardous factor of ***j*** in the working area and the probability of presence of the person in the zone of action of this factor is determined by the formula (3). And the defeatability of the hazardous factor of ***j*** is defined as:

$$P_j^{nc} = \frac{d_j}{D_j}, \tag{8}$$

where d_j – the actual level (content) of the hazardous factor (substance) of ***j***;
D_j – the limit level (content) of the hazardous factor (substance) of ***j***.
It is known that the limit level (content) of the hazardous factor (substance) of ***j*** is the level at which workers are to be quickly evacuated from the hazardous area.
If expressions for P_j^b, P_j^p and P_j^{nc}, are substituted in formula (6), the formula will have the following form:

$$P_{b_j} = \frac{t_j^b \cdot t_j^p \cdot d_j}{T_{CM}^2 \cdot D_j}. \tag{9}$$

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

$$P_b(m) = 1 - \prod_{j=1}^{m} \left(1 - P_{b_j}\right). \tag{10}$$

Consideration of the probability of staying in the zone of action of the hazardous factor of ***i*** for some workplaces regional branch of "Southern Railway" PJSC "Ukrainian Railway" are given in Table 3.

Table 3 – Quantitative assessment of potential harmfulness of industrial processes for employees with harmful working conditions

№	*Workplace, profession, workshop (section, department)*	Number of employees	*Class of working conditions*	The odds of working on the ***n*** harmful factors, P_{v_i}	*Probability of the* hazardous factor of ***j***, P_{b_j}	Integral risk, R_{int}
1.	Electric welder (engaged in cutting and manual	2	3.2	0,969918	0,287255	0,774952

	welding)					
2.	Locksmith to repair rolling stock (diesel testing)	4	3.1	0,9025	0,624808	0,001945

The data obtained as a result of the calculations show that the probability of the impact of harmful factors on the employee working in the crane shop is excessive for all employees without exception ($P_{v_i} \approx 0{,}9$). The probability of the hazardous factor of ***j*** action on the employees of the welding department, diesel department and crane repair sites in the crane shop building according to the calculations is excessive ($P_{b_j} \geq 0{,}1$). At the same time, it should be understood that the impact of harmful and hazardous industrial factors is not limited to the working area, which is defined as the area in which the workplaces of permanent or temporary (non-permanent) stay of employees during their labor activity are located [13], but is distributed in the area in accordance with the established laws. Thus, for example, the intensity of IR radiation, characterized by the density of energy flow, is determined by the following formulas [14]:

with $l \geq \sqrt{S}$

$$Q = \frac{0{,}91 \cdot S\left[\left(\frac{T}{100}\right)^4 - A\right]}{l^2}, \tag{11}$$

with $l \leq \sqrt{S}$

$$Q = \frac{0{,}91 \cdot S\left[\left(\frac{T}{100}\right)^4 - A\right]}{l}, \tag{12}$$

where Q – energy flux density, W/m^2;
S – radiation area, m^2;
T – radiation surface temperature, K;
l – radiated distance, m;
A – constant (for human skin and cotton cloth A = 85; for the cloth A = 110).
Dependence of intensity of IR radiation on distance without taking into account mutual influence for working area of electric welders (WP № 11a and WP № 11b) of the welding section of the crane shop (2 × 2 m) (p. 1 of Table 2), located opposite each other at a distance of 1.6 m, looks like the one shown in Figure 1, and testifies that at a distance of 0.95 m the normative level of intensity of IR radiation from each of the working places is already reached.

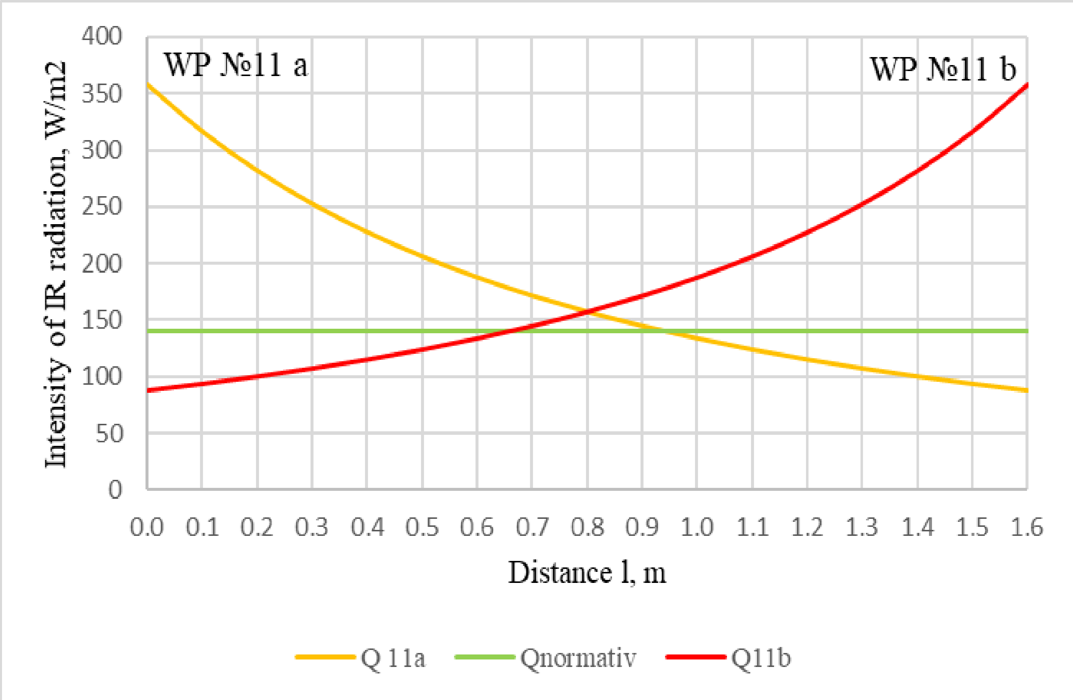

Figure 1 – Dependence of intensity of IR radiation on the distance between the working area of electric welders of WP № 11a and WP № 11b without taking into account the mutual influence

But taking into account the mutual influence of the intensity of IR radiation from both workplaces at their simultaneous work, we will have a very different picture (Figure 2). The intensity of IR radiation from both workplaces at their simultaneous work in the whole area significantly exceeds the normative level.

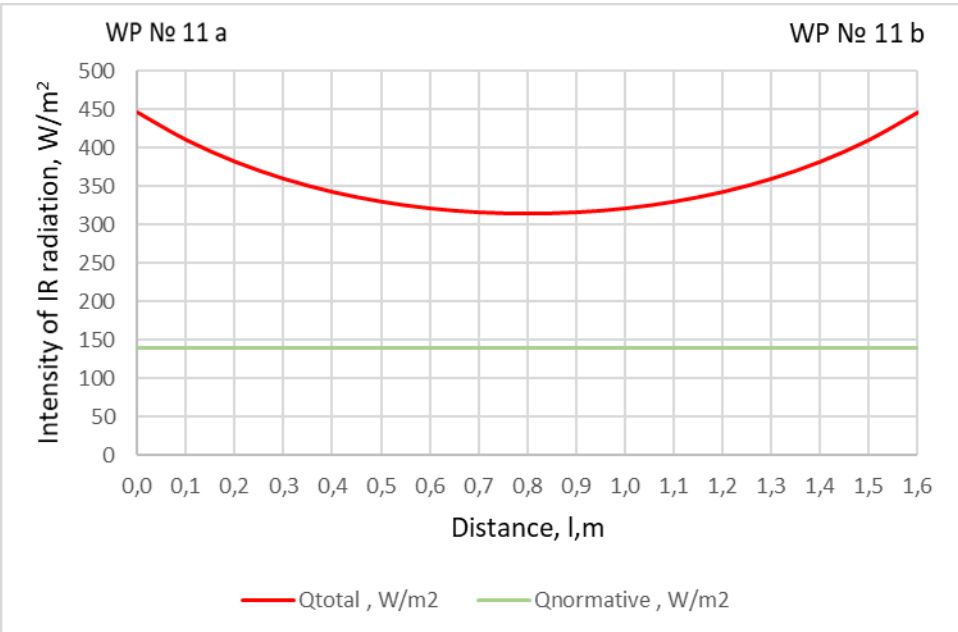

Figure 2 – Dependence of intensity of IR radiation on distance between working zones of electric welders of WP №. 11a and WP № 11b taking into account mutual influence

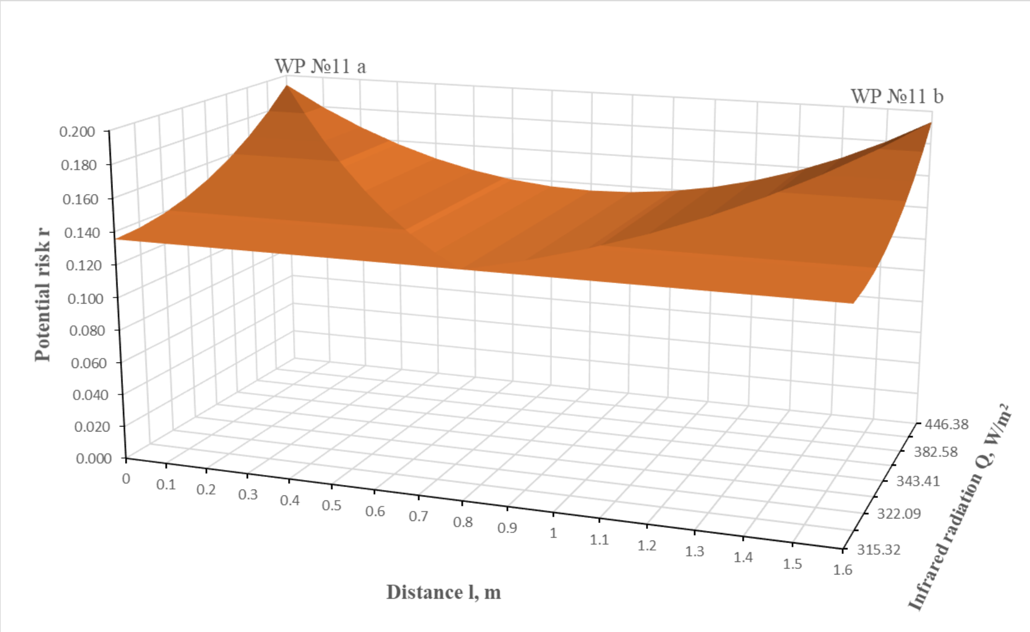

Figure 3 – The level of industrial risk for a number of electric welders' workplaces(WP №11a and WP № 11b)

Recalculation of the indicators of the industrial environment in the risk indexes for the working areas of electric welders (WP № 11a and WP № 11b) of the welding section in the building of the crane shop and the construction of a three-dimensional model of the zone of industrial risk for these workplaces shows that during the period of simultaneous work around their workplaces we have an area with an excessive level of risk ($R_{int} > 10^{-1}$) (figure 3), which is undesirable for any of the other workers. Taking into account the fact that their workplaces are located close to each other and there is no gap in the welding room, therefore, each of the employees of the industrial unit is in the zone of occupational risk for welders.

During the repair and testing of diesel engines in the working area of locksmiths to repair rolling stock (WP № 33a, WP № 33b, WP № 33c and WP № 33d) the following types of work are carried out, which are the main sources of noise: operation of the injector test bench; adjustment and adjustment of fuel pumps for flushing diesel fuel parts; operation of the crane beam; centering of a diesel engine or diesel generator; hydrotesting of a diesel engine or diesel generator; resuscitation of a diesel engine or diesel generator; running-in of a diesel engine or diesel generator.

In accordance with the Methodology for calculating the equivalent noise level, set out in [15, 16], the sound pressure levels depending on distance were calculated for the diesel department of the crane shop, taking into account the mutual influence from a number of located workplaces. In order to characterize the real mutual noise impact during the working shift on the employees of the diesel department of the crane shop, the influence of both direct and reflected sound was taken into account with the subsequent recalculation of the received data into risk indexes..

Octave levels of sound pressure L in dB in the calculated points of rooms with several noise sources should be calculated in the zone of direct and reflected sound by the formula:

$$L = 10\lg\left(\sum_{i=1}^{m}\frac{10^{0{,}1L_{wi}}\chi\,\Phi}{\Omega r^2} + \frac{4}{kB}\sum_{i=1}^{n}10^{0{,}1L_{wi}}\right) \quad (13)$$

where, L_{wi} – octave sound power level in dB, which is created by the same noise source of ***i***;
m – the number of noise sources closest to the design point (i.e. noise sources for which $r_i = 5r_{min}$, where r_{min} is the distance in *m* from the design point to the acoustic center of the closest noise source);
x – a factor that takes into account the influence of the near field when the distance *r* is less than twice the maximum source size, $r < 2l_{max}$;
Φ – the directionality factor of the noise source (in our case the source with uniform radiation, Φ = 1;
Ω – spatial angle of source, radian;
r – the distance from the acoustic center of the noise source to the design point, m;
n – total indoor noise;

k – a factor that takes into account the diffusivity disorder of the sound field in the room (taken as a function of the average absorption coefficient a_{cp});
a_{cp} – average sound absorption coefficient, which is determined by the formula:

$$a_{\text{cp}} = \frac{\text{A}}{S_{\text{orp}}} \tag{14}$$

A – equivalent sound absorption area, m^2, determined by the formula:

$$\text{A} = \sum_{i=1}^{n} a_i S_i \tag{15}$$

a_i – *i*-surface sound absorption coefficient;
S_i – *i*-th surface area, m^2;
S_{orp} – total indoor fence, m^2;
B – permanent place in m^2, which is determined by the formula:

$$\text{B} = \frac{\text{A}}{1 - \text{a}_{\text{cp}}} \tag{16}$$

If all ***n*** noise sources have the same sound power L_{wi}, respectively:

$$10\lg\sum_{i=1}^{n} 10^{0,1L_{wi}} = L_{wi} + 10\lg n \tag{17}$$

The received results testify to mutual strengthening of harmful influence of factors of the industrial environment and labour process on workers of diesel department of the crane shop. Thus, the received values of potential industrial risk in four times more than previous values ($R_{int} \approx 0{,}004 \cdot 10^{-3}$).

Based on the obtained values of the integral index of industrial risk (Table 3), a three-dimensional model of the harmful impact of industrial risk in the space between the workplaces of locksmiths to repair rolling stock in the diesel section of the crane shop building was constructed. This model gives a visual picture of hazards for the diesel department workers (Figure 4).

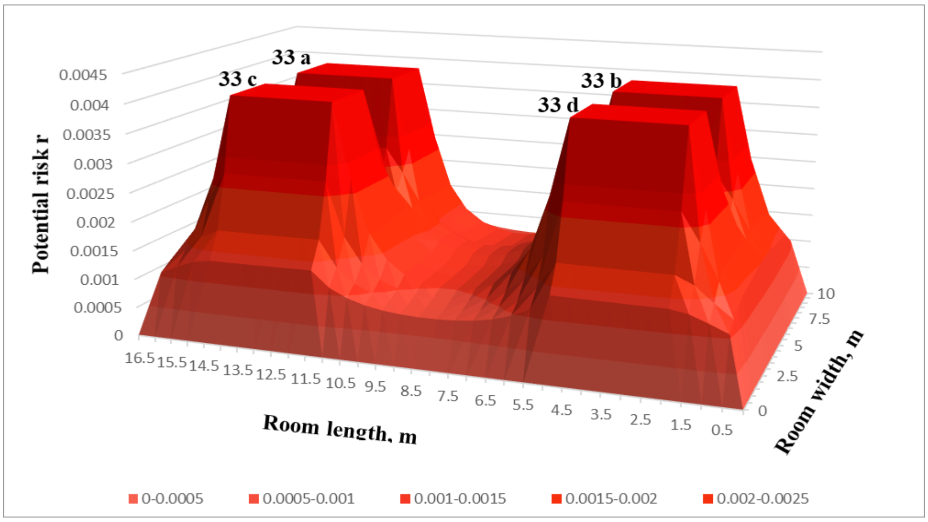

Figure 4 – The level of industrial risk for a number of locksmiths' workplaces for the repair of rolling stock (PM №33a, PM №33b, PM №33c, PM №33d)

The analysis of the received data testifies to the fact that there is an increase of mutual harmful influence at the joint action of hazardous and harmful factors. Character of performed works (change of modes at diesel engines testing) assumes occurrence of powerful reverberation. The safest zone in diesel department of crane shop is the area between the workplaces. But during the work of the test stands the situation changes radically. As a result, there is a general excess industrial risk for the diesel department employees.

As a result of the carried out research it was established that development and improvement of the risk-oriented approach consists not only in withdrawal of some insignificant harmful and hazardous industrial factors, but also in full consideration of risk-forming factors and mechanisms causing accidents.

II. Conclusions:

Application of the proposed approach allows to estimate values of potential industrial risk at any quantity of harmful and hazardous factors at workplaces, taking into account their mutual influence, to define zones with the largest levels of industrial risk between workplaces and at any distance from them, for definition of optimum and most hazardous routes of movement of workers on the territory of workshop. Thus, the substantiation of application of risk-oriented approach for application of topographic method of industrial traumatism forecasting has been determined.

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Professor Tretyakov Oleg, et. al. "Methodical Basis Of Risk-Oriented Approach To The Implementation Of Topographic Method Of Industrial Traumatism Forecasting." *IOSR Journal of Research & Method in Education (IOSR-JRME)*, 11(1), (2021): pp. 18-26.