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V. A. Tsopa[1],
orcid.org/0000-0002-4811-3712,
S. I. Cheberiachko[2],
orcid.org/0000-0003-3281-7157,
O. O. Yavorska[*2],
orcid.org/0000-0001-5516-5310,
O. V. Deryugin[2],
orcid.org/0000-0002-2456-7664,
O. M. Borovytskyi[2],
orcid.org/0000-0003-1111-7960

1 – International Institute of Management, Kyiv, Ukraine
2 – Dnipro University of Technology, Dnipro, Ukraine
* Corresponding author e-mail: elenayavorska80@gmail.com

IMPROVING A PROCESS OF MANAGING DYNAMIC OCCUPATIONAL RISKS

Purpose. To improve the process of managing dynamic occupational risks, which considers changes in time in hazardous factors of the organization's environment in the occupational safety and health management system.

Methodology. To improve the process of managing occupational risks, we have applied a well-known "Bow-Tie" model (ISO 31010:2018). The model allows assessing occupational risks as the product of the probability of hazardous event occurrence and severity of the consequences, taking into account the influence of hazardous external and internal factors, hazardous actions or dangerous inactions, which, according to the requirements of Clause 4.1 of the ISO 45001:2018 standard, are interconnected and subject to the influence of time.

Findings. A model of the connection of hazardous factors of the internal and external environment of an organization, related to their negative influence on the growing probability of hazardous event (incident) occurrence and a degree of severity in time, has been developed. The process of managing occupational risks is proposed, taking into account changes in the time of exposure to hazardous factors, which will allow determining the acceptability or unacceptability of the occupational risk in time. The analysis of changes in occupational risks is proposed to be considered in the following time intervals (specifically in those where there is a corresponding change in risk factors): time of the day, day of the week, month of the year, quarter, half year, year, years etc. All the proposed professional risks were divided into two groups of professional risks considering the changes in their levels in time: static and dynamic ones. To calculate the occupational risk level, it is also proposed to determine all combinations of hazardous factors that can occur simultaneously in time within the corresponding intervals of the time under analysis.

Originality. It has been determined that identification of the acceptable level of an occupational risk in the maximum combination of all hazardous factors acting simultaneously at a certain point in time will lead to the fact that all other combinations of hazardous factors will also have an acceptable level of occupational risk. This provision follows from the fact that the level of occupational risk from a smaller number of hazardous factors will not exceed the indicator of occupational risk from the exposure to a larger number of hazardous factors in time.

Practical value. The forms for dynamic occupational risk assessment have been developed; a matrix has been proposed for determining the number of combinations of hazardous factors acting simultaneously in time.

Keywords*: hazardous factor, incident, occupational risk, safety of work*

Introduction. The process of managing occupational risks (OR) is widely used in occupational safety and health management systems (OSHMS) to substantiate management decisions on reducing the level of injuries and occupational diseases [1, 2]. There are various tools, which can be selected by organizations with no legislation limits [3, 4]. An important condition for choosing one or another approach is the reduction of ORs according to the working conditions that have developed at a specific enterprise. It is usually carried out in several steps: identification of occupational risks and hazardous factors (HF), determination of the consequences for employees, immediate evaluation of OR, substantiation of preventive and protective measures, and verification and improvement of the previous stages [5, 6]. However, the standardized methods of OR assessment do not consider HF changes in time, i.e. changes in the current state of some object (equipment, production operation) or subject (employee), possible anomalous phenomena (events), malfunctions or errors that can appear from time to time when production tasks are being performed . Recently, considerable attention has been paid to solving this problem. New approaches to the identification of hazards and HFs have been proposed [7]. The latest algorithms have been developed for evaluating the influence of dynamic working conditions on the OR magnitude (e.g. for firefighters, military, and policemen) [8]; new ways have been defined to substantiate the models for evaluating the combined impact of several hazards on the probability of dangerous event occurrence [9, 10], etc. That indicates an increased interest in the solution of the described task of managing and evaluating dynamic ORs: elaboration of an understandable, uncomplicated mechanism that would allow substantiating managerial decisions to improve a safety level at workplaces in the production conditions and without complex mathematical models.

Literature review. The analysis of scientific research showed that the "Dynamic risk assessment" (DRA) method is often used for critical infrastructure objects [11]. The most widespread among them is the "Barrier and operational risk analysis method" (BORA) [12, 13] as well as the risk modelling method by integrating organizational, human, and technical factors (risk-OMT) [14]. However, although their algorithm includes an element that reflects possible changes in the detected danger in time, their shortcomings include the need to update periodically the OR value, accompanied by possible assumptions about the probability that their value can be influenced by various organizational and operational factors. In addition, researchers/practitioners pay attention to the complexity of processing raw data, especially with a significant number of influences [15, 16] and the need for constant training of practitioners, which would explain possible deviations from the basic approach to calculations [17]. To eliminate the above-mentioned shortcomings, a new approach called the OR "barometer" appeared. When evaluating OR, it considers complex impact of the psychological state of operators, a production process, and a level of information technology, making it possible to come to a balanced decisions concerning working periods, reduced technological losses, increased safety level, etc. [18, 19]. The approach requires real-time monitoring of influence factors; that needs significant financial costs for its implementation and maintenance. Some researchers note that the introduction of this concept is accompanied by a constant increase in both material and financial resources. This is due to the growing amount of data that needs to be processed in real time, characterizing the state of protective barriers and operational conditions [20]. It is highlighted that due to significant financial requirements, the RB method is used mainly in the oil and gas industry [21, 22], where even a small error or deviation can lead to colossal losses. The main advantage of the RB method is constant visualization of the OR value results, helping the staff monitor their possible changes in time [23]. However, the disadvantage of this method is lack of distribution of ORs by the time of their changes, which complicates their processing and analysis resulting in unrealistic assumptions.

The analysis of recent scientific works on the DRA assessment indicates a significant number of different approaches used to solve a problem of risk management, based on specific operating conditions, which requires the development of a universal approach to be adapted quickly to one or another sphere of human activity.

Purpose. The purpose of the paper is to improve a process of OR management, taking into account changes of HFs in the workplace environment in time.

Methods. It is proposed to carry out the assessment of OR hazards basing on the "Bow-Tie" model [24]. It is one of the most widespread models owing to its convenience and simplicity of presentation of the cause-and-effect relationship between a hazard, a hazardous event, and consequences. In particular, the diagram makes it possible to consider several different scenarios of the event development [25]. Moreover, its visualization allows clearly demonstrating the process of OR control by defining the number of barriers (protective or preventive measures) placed on the path between a hazard and a hazardous event and a hazardous event and its consequences.

The number of barriers allows identifying an estimate of preventive and protective measures for labour protection, on the one hand, and influencing the probability of hazardous event occurrence, on the other hand. To determine the latter, the "As low as reasonably practicable" (ALARP) principle is used; it is based on the principle that the residual risk level should be reduced as much as it is practically possible [26]. The represented model (Fig. 1) features as follows. It helps consider the influence of all external and internal HFs that increase the probability of hazardous event occurrence or severity of the consequences in OSHMS according to the requirements of Clause 6.1 of the International Standard ISO 45001:2018, which indicates the need for hazard analysis from the internal and external environment of an organization (Fig. 2).

Moreover, the model differs from the available ones (e.g. method of graphs, whose essence is in consideration of a cyclic alternative network system; method for searching for optimal strategy based on the probabilistic temporal logic; method involving theory of games and others) [27] in the specific OR

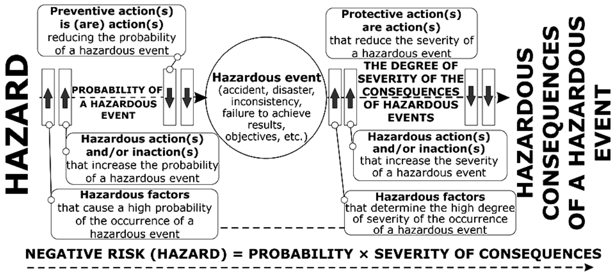

Fig. 1. Model of OR control while changing the factors of internal and external environment of an organization

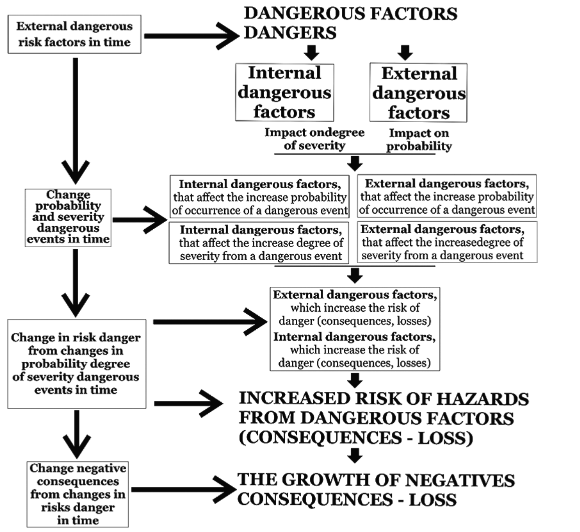

Fig. 2. Model of relation between the factors of organization's environment connected with their time effect and the resulting OR changes in time

calculation. It is calculated as the product between the total coefficient of the hazardous event severity, determined by identifying all hazardous external and internal factors (physical, chemical, climatic, biological, psychophysiological, ergonomic, technical, organizational, etc.) and hazardous events of the workers (errors, malicious intent, inconsistency) at an organization.

The proposed model of the connection of HFs in time will help reduce uncertainty in OR assessment owing to a comprehensive consideration of the effects of combinations of hazardous external and internal factors or hazardous actions and inactions that occur in different periods of time [28].

In order to achieve the goal of improving the process of OR control, taking into account changes in HF in time, there is a need to divide them into two groups (Table 1):

- static (unchangeable) ORs, which do not change in time, and if they change, it happens no more than once a year (e.g. once every one and a half year, two or three years, etc.);

- dynamic (changeable) ORs, which change in time more than once a year (e.g. more than once per hour, per work shift (8 hours), night or day (morning, day, evening shifts), weekdays (working days, holidays or weekends), week, month, season, quarter, half year and year.

Table 1

Classification of ORs changeable in time

No.	OR type	OR changes in time	Examples of OR changes in time
1	Dynamic OR	*More than once a year*	Time of the day: from $00.^{00}$ till $24.^{00}$
			Time of the day: morning $06.^{00}$–$12.^{00}$; afternoon $12.^{00}$–$18.^{00}$; evening $18.^{00}$–$24.^{00}$; night $00.^{00}$–$06.^{00}$
			Days of week: Monday, Tuesday, Wednesday, Thursday, Friday, Saturday, Sunday
			Days: weekdays, weekends, holidays, after holidays
			Seasons: spring, summer, autumn, winter Quarter
2	Static OR	*Less than once a year*	Year, 2 years and more

The distribution allows improving the qualitative and quantitative analysis of OR as well as strengthening the OR monitoring by paying more attention to the HF variables that leads to a change in the OR level at the specified time intervals (Fig. 3). For example, when carrying out transport work, the OR level due to occurrence of a traffic accident increases significantly during a winter period as a result of worsening weather conditions (e. g. ice), which are absent during other seasons, where the risk is reduced to an acceptable level (Fig. 4). A similar conclusion can be made when analysing the OR level hourly per day (Fig. 5), e. g. caused by a change in the psychophysiological state (accumulation of fatigue, deterioration of the reaction, increased nervous tension, etc.).

It should be noted that the assessment of dynamic PRs is peculiar in the fact that HFs can appear both separately at certain intervals of time and together, forming a "cumulative" effect; it requires that all combinations of the event development be worked out for the OR calculation. We emphasize the expediency of such an approach, since the occurrence of a hazardous event, more likely under the action of a number of OPs that are not paid due attention, leads to the manifestation of predictable circumstances [29]. In addition, according to the requirements of ISO 45001:2018, an organization must consider all possible options for the occurrence of hazardous events (Fig. 6).

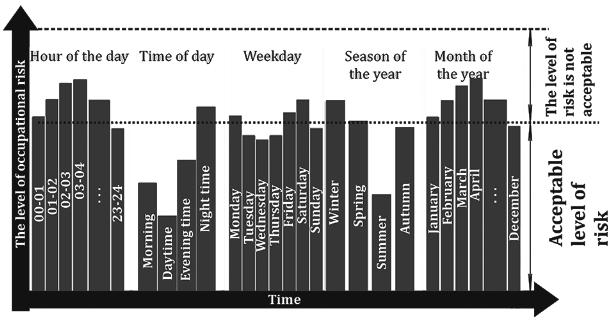

Fig. 3. OR changes in time: hour of the day, time of the day, weekday, season, month

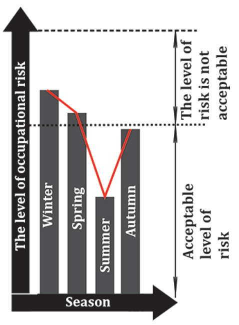

Fig. 4. Example of changes in the dynamic OR level of a driver in terms of seasons

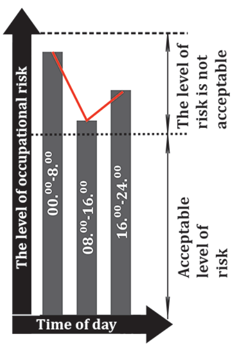

Fig. 5. Changes in the dynamic OR level of a driver in terms of time of day

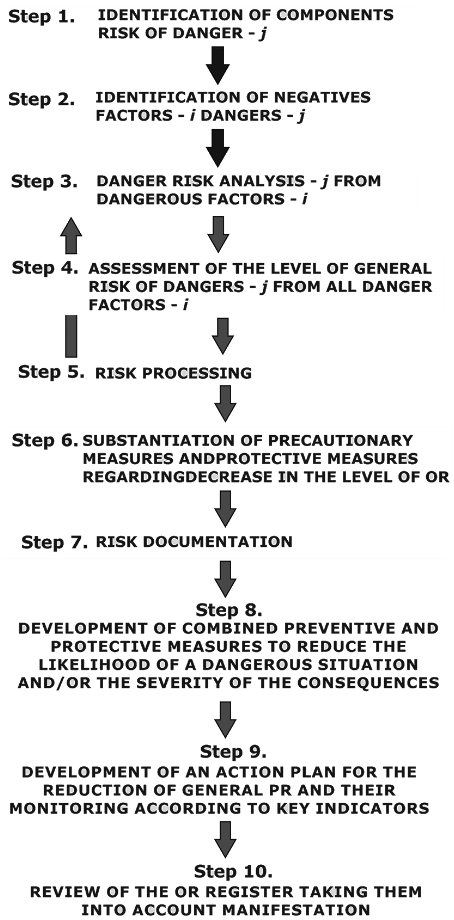

Fig. 6. Improved process of OR management taking into account possible combinations of OR levels growing due to simultaneous effect of HFs per certain period of time

The proposed process of managing dynamic ORs involves the sequential execution of eleven steps. One of the main ones is the analysis of the production situation, identification of hazards and HFs, and substantiation of preventive or protective measures to increase the OSHMS effectiveness.

The first step is to identify the hazard, hazardous event and consequences of the hazardous event resulting from the development of cause-and-effect relationships between the hazard and hazardous event. To complete this step, various methods of information collection are used, e. g. analysis of documentation, observation, experiment, statistical data of accidents etc. During the second step, we form a register of HF, hazardous actions or inactions that increase the probability of the hazardous event occurrence and severity of the consequences. For this step, you can use such methods as SWOT analysis, PEST analysis or PIMS analysis, questionnaires, observations, employee surveys, discussions etc. As a result, we form an appropriate register of HFs, which can be divided conveniently into several groups: human, organizational, ergonomic, technical, and others.

In terms of the third step, dynamic and static ORs are identified according to the criteria indicated in Table 1. We carry out a procedure for ranking HFs using any suitable method, e. g. Decision Making Trial and Evaluation (DEMATEL) based on paired comparison and decision-making tools relying on the graph theory or the Analytic Network Process (ANP) method, which involves decision-making based on a fuzzy representation of criteria evaluations. That will result in the establishment of causal HFs characterized by a significant impact on the probability of hazardous event occurrence.

The fourth step deals with the analysis of action of HFs from 1 to 10 with the determination of all possible combinations of their relations in time (Table 2). To do this, we can use formula

$$C_n^m = n!/(m!\times(n-m)!), \quad \text{here } C_n^0 = 1,$$

where n is the total number of HFs; m is the number of combination of simultaneous effects of HF_i in time t_i.

In terms of the fifth step, we conduct an OR analysis by defining the probability of hazardous event occurrence and severity of the consequences of HF_i impact; HF_i impact changes over time. To do this, you can use a matrix approach (a matrix of 5 × 5 or 6 × 6).

Consider the example. A calculation of the hazard risk from the action of a specific HF was carried out using a 10×10 matrix, where 1 is the probability or severity of the consequences is unlikely or insignificant, respectively, and 10 indicates that the event will definitely occur, while severity of the consequences will be catastrophic (disability or death). Points between 1 and 10 are chosen according to the experts' understanding of the current situation based on statistical data, analysis of the current situation etc. At the same time, to reduce uncertainty in the experts' assessments, it is possible, for instance, to use an acceptable method (e.g. the Grubbs criterion).

We calculate OP assessment of the j^{th} hazard in terms of the i^{th} HF_i with the help of the known formula as the product of probable occurrence of a hazardous event and severity of the consequences

$$R_{ji} = B_{ji} \times T_{ji},$$

where R_{ji} is OR of a hazardous event due to hazard j considering a hazard factor HF_i; B_{ji} is probability of the hazardous event occurrence due to hazard j affected by hazard factor i; T_{ji} is degree of severity of the consequences due to hazardous event j under the effect of HF_i.

During the sixth step, we evaluate the overall OR level. For example, it is acceptable if the total number of calculated points for all HFs is within the specified limits (less than 40 points); it is unacceptable if the total number of calculated points for all HFs exceeds the critical indicator (more than 60 points); and it is acceptable with verification if the total number of calculated points for all dangerous factors is in the range (from 40 to 60 points). The critical value of unacceptable risk of 60 points was selected according to the parameters of the acceptable matrix (10 × 10). The risk from one HF can already lead to an unacceptable risk. However, it should be taken into account what can happen when the risks of HFs are acceptable, and the overall risk, in its sum, is not acceptable; thus, it is necessary to implement preliminary actions to reduce the overall risk by reducing the risk from HFs.

The seventh step is designed to substantiate preventive and protective measures to reduce the OR level in accordance with OR hierarchy, which is represented in the ISO 45001:2018 standard.

The eighth step is devoted to OR documenting. For the convenience of OR assessment, we offer a special form of the map (Table 3) where there is a separate column *6* to take into account HF_i changes in time. In addition, there is a place for each HF_i for determining the probability of hazardous event occurrence *7*, degree of the consequences severity *8*, and OR magnitude *9*, which are then summed up to determine the total OR.

If an unacceptable level of OR is detected, we proceed to the ninth step, which involves the development of combined preventive and protective measures to reduce the likelihood of a hazardous situation and/or severity of the consequences. During the tenth step, an action plan is elaborated to reduce the total ORs and monitor them according to key indicators. The last step is devoted to the review of the register of ORs determined with the consideration of their manifestation in time, i.e. static (at least once a year) and dynamic, depending on the frequency of manifestation (once a week, month, six months, year).

Table 2

Example of determining a matrix of the number of combinations K of the simultaneous effect from 1 to 10 HFs n in time

m – number of HFs	C_n^m	n – total number of HF_i									
		1	2	3	4	5	6	7	8	9	10
0	C_{10}^0	1	1	1	1	1	1	1	1	1	1
1	C_{10}^1	1	2	3	4	5	6	7	8	9	10
2	C_{10}^2	–	1	2	6	10	15	21	28	36	45
3	C_{10}^3	–	–	1	4	10	20	35	56	84	120
4	C_{10}^4	–	–	–	1	5	15	35	70	126	210
5	C_{10}^5	–	–	–	–	1	6	21	56	126	252
6	C_{10}^6	–	–	–	–	–	1	7	28	84	210
7	C_{10}^7	–	–	–	–	–	–	1	8	36	120
8	C_{10}^8	–	–	–	–	–	–	–	1	9	45
9	C_{10}^9	–	–	–	–	–	–	–	–	1	10
10	C_{10}^{10}	–	–	–	–	–	–	–	–	–	1
Number of combinations		2	4	7	16	32	64	128	256	512	1024

Results. Consider the hazard "tree" that falls on a feller, while the hazardous event is "a tree falling on a feller" working in forestry. A tree is a hazard, a hazard event (incident) is a tree or its part falling on a feller; the consequences are injuries to the feller. The main HFs that were determined as a result of processing the previous stages of the described algorithm (Fig. 6): include: HF_1 "inappropriate physical state of the feller", HF_2 "inappropriate state of the tree", HF_3 "inappropriate working environment", HF_4 "inappropriate technical equipment of the feller". The OR magnitude of a specific HF was calculated according to the above formula (2) using a ten-point matrix. The results of the calculations are given in Table 4.

The specified approach of OR management allows establishing any effects of HF on the probability of hazardous event occurrence and its severity of consequences, which is its main difference from the known methods.

This allows us to consider a certain chain of combination or sequential manifestation of HFs, which in most cases can lead to an unacceptable OR. The resulting table for the evaluation of the OR for the feller is shown in Table 6.

To evaluate OR due to certain hazard j, identify the number of combinations using formula (1) of four factors: HF_i, HF_i HF_i, and HF_i (Table 4), making up 16 combinations of single action for those four HF_i in time (Table 5). Contrary to the previous OR assessment, involving only determination of HF manifestation within certain periods, the OR evaluation considering all possible combinations of simultaneous HF_i action in time has resulted in identifying the unacceptable OR level. That requires implementation of combined preventive actions. For instance, it can be implementation of simultaneous control over physical state of the feller, weather conditions for the planned operation, and appropriate equipment. If two HFs are observed simultaneously, the operation stops. Moreover, a combined approach to support an adequate level of labour safety means the availability of emergency medical treatment

Table 3

Registration form to assess OR. Calculation of OR_{ji} due to each HF_{ji} assuming that they act separately from each other in time

No. of hazard	Identification			Determining the OR level of hazard j due to HF in time t_m					Primary assessment of the OR level due to corresponding HF_{ji} (unacceptable if it is higher or equals to 60; acceptable if it is less than 60)
				Time t of the NF effect	Time	Determining the HF effect		OR due to hazard j considering HF_i	
	Hazard	Hazardous event (incident)	Negative consequences	HF_{ji}	t_i	Probability of the hazardous event occurrence	Degree of severity of the hazardous event consequences		
Calculation of OR_{ji} due to each $HF_{ji,}$ assuming that they act separately from each other in time									
j	H_j	Hazardous event j	NC_j	HF_{j1}	t_1	B_{j1}	T_{j1}	R_{j1}	Acceptable/unacceptable
				HF_{j2}	t_2	B_{j2}	T_{j2}	R_{j2}	Acceptable/unacceptable
				HF_{j3}	t_3	B_{j3}	T_{j3}	R_{j3}	Acceptable/unacceptable
				...	....	...	...	...	Acceptable/unacceptable
				HF_{jn}	t_n	B_{jn}	T_{jn}	R_{jn}	Acceptable/unacceptable
Calculation of total OR_{ji} if all possible $HF_{ji,}$ combinations act simultaneous in time									
Calculations of a simultaneous action of HFs – HF_{ji}				Time of HF_i action, t_i		Total OR_{ji} – R_j in terms of simultaneous HF_{ji} action in time			Primary assessment of the OR level due to simultaneous action of different HF_{ji} combinations in time
No.	n	C_m^n							
1	0	C_m^0		t_i		R_j			Acceptable/unacceptable
...	...	...							
$n-1$	$n-1$	C_m^{n-1}							
$n+1$	n	C_m^n							

Table 4

Results of the calculation of OR level, R_{ji}, due to HF_i

HF_i	HF_i title	OR_i due to HF_i
HF_1	Inappropriate physical state of the feller	$R_{j1} = 30$
HF_2	Inappropriate state of the tree	$R_{j2} = 35$
HF_3	Inappropriate working environment	$R_{j3} = 40$
HF_4	Inappropriate technical equipment of the feller	$R_{j4} = 45$

in case of the hazardous event occurrence and a response team to save or support a worker during or after the incident occurrence.

The indicated approach to OR management makes it possible to identify any HF effects on the probability of accident occurrence and its consequences; it is the main difference of the method from the others currently known. That helps consider certain chain of combination or sequential manifestation of HF that in most cases can result in unacceptable OR. Table 6 summarizes the OR assessment for the feller.

Table 5

Determining the level of OR_i (R_j) in time, t_i, due to all combinations of simultaneous HF action

No. of combination	HF				Determining the OR level simultaneously and not simultaneously in time t	OR value	OR assessment: unacceptable if it is more than 60\acceptable is it is less than 60
1	Does not act	Does not act	Does not act	Does not act	0		Acceptable
2	Acts	Acts	Acts	Does not act	$R_{j123} = R_{j1} + R_{j2} + R_{j3}$	105	Unacceptable
3	Acts	Acts	Does not act	Acts	$R_{j124} = R_{j1} + R_{j2} + R_{j4}$	110	Unacceptable
4	Acts	Does not act	Acts	Acts	$R_{j134} = R_{j1} + R_{j3} + R_{j4}$	125	Unacceptable
5	Does not act	Acts	Acts	Acts	$R_{j234} = R_{j2} + R_{j3} + R_{j4}$	120	Unacceptable
6	Does not act	Does not act	Acts	Acts	$R_{j34} = R_{j3} + R_{j4}$	85	Unacceptable
7	Does not act	Acts	Does not act	Acts	$R_{j24} = R_{j2} + R_{j4}$	80	Unacceptable
8	Does not act	Acts	Acts	Does not act	$R_{j23} = R_{j2} + R_{j3}$	75	Unacceptable
9	Acts	Does not act	Does not act	Acts	$R_{j14} = R_{j1} + R_{j4}$	75	Unacceptable
10	Acts	Does not act	Acts	Does not act	$R_{j13} = R_{j1} + R_{j3}$	70	Unacceptable
11	Acts	Acts	Does not act	Does not act	$R_{j12} = R_{j1} + R_{j2}$	65	Unacceptable
12	Does not act	Does not act	Acts	Does not act	R_{j3}	40	Acceptable
13	Does not act	Acts	Does not act	Does not act	R_{j2}	35	Acceptable
14	Acts	Does not act	Does not act	Does not act	R_{j1}	30	Acceptable
15	Does not act	Does not act	Does not act	Act	R_{j4}	45	Acceptable
16	Acts	Acts	Acts	Acts	$R_{j1234} = R_{j1} + R_{j2} + R_{j3} + R_{j4}$	150	Unacceptable

Table 6

Registration form (maps) to assess OR. Calculation of OR_{ji} due to each HF_{ji} assuming that they act separately from each other in time

No. of hazard	Identification			Determining the OR level of hazard j due to HF and in time t_m					Primary assessment of the OR level due to corresponding HF_{ji}
				Time t of the HF effect	Time	Determining the HF effect		OR due to hazard j considering HF_i	
	Hazard	Hazardous event (incident)	Consequences of the hazard event	HF_{ji}	Time of HF_i action, t_i	Probability of the hazardous event occurrence	Severity degree of the hazardous event consequences		
1. Calculation of OR_{ji} due to each HF_{ji}, assuming that they act separately from each other in time									
j	H_j	HF_j	Consequences j	HF_{j1}	t_1	5	6	$R_{j1} = 30$	Acceptable/unacceptable
				HF_{j2}	t_2	7	5	$R_{j2} = 35$	Acceptable/unacceptable
				HF_{j3}	t_3	5	8	$R_{j3} = 40$	Acceptable/unacceptable
				HF_{jn}	t_4	5	9	$R_{j4} = 45$	Acceptable/unacceptable

2. Calculation of total OR_{ji} if all possible HF_{ji}, combinations act simultaneously in time

No. of the combination of simultaneous action of HFs – HF_{ji}	Time	Total OR_{ji} – R_j in terms of simultaneous HF_{ji} action in time	Primary assessment of the OR level due to simultaneous action of different HF_{ji} combinations in time
1	0	0	Acceptable
2	$t_1 = t_{j2} = t_3$	$R_{j123} = R_{j1} + R_{j2} + R_{j3} = 105$	Unacceptable
3	$t_1 = t_{j2} = t_4$	$R_{j124} = R_{j1} + R_{j2} + R_{j4} = 110$	Unacceptable
4	$t_1 = t_3 = t_4$	$R_{j134} = R_{j1} + R_{j3} + R_{j4} = 125$	Unacceptable
5	$t_{j2} = t_3 = t_4$	$R_{j234} = R_{j2} + R_{j3} + R_{j4} = 120$	Unacceptable
6	$t_3 = t_4$	$R_{j34} = R_{j3} + R_{j4} = 85$	Unacceptable
7	$t_{j2} = t_4$	$R_{j24} = R_{j2} + R_{j4} = 80$	Unacceptable
8	$t_{j2} = t_3$	$R_{j23} = R_{j2} + R_{j3} = 75$	Unacceptable
9	$t_1 = t_4$	$R_{j14} = R_{j1} + R_{j4} = 75$	Unacceptable
10	$t_1 = t_3$	$R_{j13} = R_{j1} + R_{j3} = 70$	Unacceptable
11	$t_1 = t_{j2}$	$R_{j12} = R_{j1} + R_{j2} = 65$	Unacceptable
12	t_3	$R_{j3} = 40$	Acceptable
13	t_{j2}	$R_{j2} = 35$	Acceptable
14	t_1	$R_{j1} = 30$	Acceptable
15	t_4	$R_{j4} = 45$	Acceptable
16	$t_1 = t_{j2} = t_3 = t_4$	$R_{j1234} = R_{j1} + R_{j2} + R_{j3} + R_{j4} = 150$	Unacceptable

While analysing combinations of simultaneous exposure to HFs, it is possible to reach a conclusion and formulate an axiom (proposition) when considering dynamic ORs: if the maximum level of OR is acceptable at the simultaneous action of all four HFi at some point, then all risk levels of all other combinations of simultaneous exposure will also be acceptable.

Discussion. The results obtained from the OR evaluation, taking into account the HF_i change in time, as well as manifestation of various combinations of their simultaneous action, made it possible to identify an unacceptable level of OR, which could not be established using any other methods. As Table 6 demonstrates, the risk level from each HF separately is acceptable, but all their combinations are already an unacceptable risk. Even during the assessment of their influence in time (Table 5), it also did not allow establishing critical indicators, which led finally to erroneous decisions on the substantiation of precautionary measures.

There are quite a large number of examples of properly conducting OR assessment, which did not allow avoiding the hazardous event occurrence. In such cases, they start talking about the "black swan" or "gray rhinoceros" effect [21]. In other words, there are difficulties in recognizing the cumulative effect of HFs that increase the hazardous event probability. The proposed approach to the control of dynamic OR makes it possible to consider the development of events according to various scenarios in a certain period of time, which will avoid such errors. Its main advantage is the absence of cumbersome calculations since the division of all ORs into the static and dynamic ones made it possible to pay more detailed attention to those HF_i that vary constantly in time.

In most cases, production processes are dynamic; thus, to represent the changeable nature of the tendency of OR accumulation, scientists started active search for new models with the substantiation of labour safety systems, allowing constant introduction of changes and getting the planned result of reduced injuries [22, 23].

Note that large, powerful enterprises with a significant number of employees can detect changes and make corrections in advance, unlike small enterprises, which find it quite difficult to monitor changes and reflect them in the relevant OR maps. Therefore, the two-type classification of risks makes it possible to draw more attention to the dynamics of the technological process and those HF_i that are significant. This approach reduces the burden on experts and allows for a more detailed consideration and research on only those HFs that change in time. On the other hand, it increases the amount of various document circulation, including maintenance of OR registers (maps) – dynamic and static – that requires regular review and updating. It should be done at least once a month for the first ones (maybe more, depending on the time of HF change) and at least once a month or no more than once a year for the second ones.

The peculiarity of this approach which distinguishes it from other models for OR evaluation, e.g. from the simulation method (using a mathematical model with a random number generator [31]), is in the study of all combinations of simultaneous occurrence of several HF_i in a certain period. Moreover, the total OR magnitude can significantly exceed the level of the acceptable limit, which cannot be established when building a simulation model where there is no toolkit for calculating combinations of the HF_i influence. Therefore, during the development of a hypothesis, which should explain the dynamics of a certain process, there is a possibility of establishing inverse relations between the HF_i that occur at a certain moment in time and can change the probability of the hazardous event occurrence and severity of the consequences. However, their definition does not allow taking into account the combined effect of several HF_i; it only allows assessing their mutual influence. There is no doubt that the development of a dynamic model makes it possible to trace the cause-and-effect relationships of HF_i with a hazardous event, but the existing limitations of the adopted hypothesis prevents us from evaluating the total effect of all HF_i. The complexity of this approach should include consideration of all possible HF_i combinations, which requires further ranking of their impact and understanding of the determination of the occurrence in time of their cumulative effect on the probability of hazardous event occurrence and severity of its consequences at a specific workplace.

Conclusions.

1. A model of the connection of HFs of the internal and external environment of an organization related to their negative influence on the increasing probability of the hazardous event (incident) occurrence and the severity degree in time has been developed.

2. It has been proposed to improve the process of OR control taking into consideration the time of HF_i influence, which will make it possible to determine acceptability or unacceptability of the risk in time.

3. It has been proposed to divide all ORs into two groups paying attention to changes in their levels in time (static and dynamic) and establish the following criteria for the time of HF_i changes:

- for dynamic ORs in time, it is suggested to consider the following time intervals when there is a change in HF_i: hour of the day, time of the day, day of the week, week; season, quarter, half year, year;

- for static ORs in time, it is suggested to consider the following time intervals when there is a change in HF_i: more than a year.

4. It has been offered to calculate the OR magnitude to determine all HF_i combinations that can occur simultaneously in time by calculating the n-factorial.

5. It has been determined that identification of the acceptable level of an OR in the maximum combination of all HFs acting simultaneously at a certain point in time will lead to the fact that all other combinations of HFs will also have an acceptable level of occupational risk. This provision follows from the fact that the level of OR from a smaller number of HFs will not exceed the indicator of OR from the exposure to a larger number of HFs in time.

6. Forms for the OR assessment have been developed, and a matrix has been proposed for determining the number of combinations of possible simultaneously acting HFs.

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Удосконалення процесу керування динамічними професійними ризиками

В. А. Цопа[1], *О. О. Яворська*[*2], *С. І. Чеберячко*[2], *О. В. Дерюгін*[2], *О. М. Боровицький*[2]

1 – Міжнародний інститут менеджменту, м. Київ, Україна
2 – Національний технічний університет «Дніпровська політехніка», м. Дніпро, Україна
[*] Автор-кореспондент e-mail: elenayavorska80@gmail.com

Мета. Удосконалення процесу керування динамічними професійними ризиками, в якому враховуються зміни в часі небезпечних чинників середовища організації в системі управління безпекою праці та здоров'я.

Методика. Для вдосконалення процесу керування професійними ризиками скористались відомою моделлю «Краватка-Метелик» (IEC 31010:2019), що дозволяє оцінити професійний ризик як добуток вірогідності настання небезпечної події та тяжкості наслідків від неї з урахуванням впливу небезпечних зовнішніх і внутрішніх чинників, небезпечних дій чи небезпечної бездіяльності, які, відповідно до вимог п. 4.1 стандарту ISO 45001:2018, пов'язані між собою й піддаються впливу часу.

Результати. Розроблена модель зв'язку небезпечних чинників внутрішнього й зовнішнього середовища організації, пов'язаних з їх негативним впливом на зростання вірогідності настання небезпечної події (інциденту) та ступеня тяжкості в часі. Запропоновано процес керування професійними ризиками з урахуванням зміни часу впливу небезпечних чинників, що дасть змогу визначенню прийнятності чи неприйнятності професійного ризику в часі. Аналіз зміни професійних ризиків пропонується розглядати в наступних проміжках часу (саме в тих, де є відповідна зміна небезпечних чинників): година доби, день тижня, місяць року, квартал, півріччя, рік, роки тощо. Запропоновано всі професійні ризики поділити на дві групи професійних ризиків з урахуванням змін їх рівнів у часі: статичні й динамічні. Також для розрахунку рівня професійного ризику визначати всі комбінації небезпечних чинників, які можуть виникати одночасно у відповідних інтервалах часу, що розглядаються.

Наукова новизна. Установлено, що в разі виявлення прийнятного рівня професійного ризику від виявленої небезпеки з урахуванням впливу на ймовірність настання небезпечної події максимальної кількості всіх небезпечних чинників, одночасно діючих у визначний момент часу, можна стверджувати, що вплив усіх інших комбінацій визначених небезпечних чинників не призведе до перевищення визначеного рівня ризику, оскільки рівень професійного ризику від меншої кількості небезпечних чинників ніколи не перевищить показник ризику від впливу більшої кількості небезпечних чинників.

Практична значимість. Розроблені форми з оцінки динамічного професійного ризику, запропонована матриця для визначення кількості комбінацій небезпечних чинників, одночасно діючих у часі.

Ключові слова: *небезпечний чинник, інцидент, професійний ризик, безпека праці*

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