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Development of system of automated occupational health and safety management in enterprises

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ABSTRACT

Purpose: Develop a system of automated occupational health and safety management to improve the procedure for minimizing occupational risks and ensure comprehensive protection of employees from the impacts of negative factors of the systems "man - machine - environment".

Design/methodology/approach: The following set of scientific methods was used in the study: analysis of normative-legal documents and scientific-technical literature in the field of building and functioning of occupational safety and health management systems, methods of system analysis, simulation methods, namely discrete-event simulation (DES) of random and dynamic processes, methods of decision theory and data mining.

Findings: Based on the results of the research, a system of automated occupational health and safety management, which due to the connection the functionally independent elements (according to a certain scheme) allows to provide comprehensive protection of employees from the impacts of negative factors of the system "man - machine - environment" and reduce occupational injuries and diseases, was developed. This is done by constant monitoring and promt correcting of parameters of impact on the employee of the specified factors. The developed system was implemented in the occupational health and safety management system of the industrial enterprise "Stalkanat-Silur" (Odessa, Ukraine), resulting in reducing the number of accidents, in particular, in dangerous areas of production by 33.3%, increasing the economic efficiency of the enterprise through increasing the level of productivity by 5% and reducing in the number of social insurance payments by 11%.

Research limitations/implications: The developed system can be implemented both within separate industrial premises and in the enterprise as a whole, but the number of its elements could be changed (increase / decrease) depending on the number of jobs and dangerous areas that need control.

Practical implications: The implementation of the proposed system allows to increase the level of economic efficiency of the enterprise by increasing the level of labor productivity due to reducing the negative impact on the employee of harmful factors and compliance with rational mode of work and rest in each workplace, as well as by reducing the number of social insurance payments due to reducing the occupational injuries and diseases.

Originality/value: For the first time the system of automated occupational health and safety, which, in contrast to existing automated occupational risk minimization systems and traditional occupational health and safety management systems, provides comprehensive protection of employees from the the impacts negative factors of the system "man - machine-environment", by constant monitoring the parameters of such impact and their prompt correction in case of deviation of the specified parameters from the set criteria, was developed and proposed for use at enterprises, institutions and organizations.

Keywords: Safety and health management, Automated occupational health and safety management, Occupational risk, "Human factor", System "man - machine - environment"

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INDUSTRIAL MANAGEMENT AND ORGANISATION

1. Introduction

The main task of the functioning of occupational health and safety management systems in enterprises (OHSMS) is to provide the safe and healthy working conditions for each employee. According to the recommendations of international standards, such conditions should be provided by objective occupational risk forecasting resulting from impact of negative factors (NF) of the system "man – machine – environment" on the employee and with effectively minimize such impact through the development and implementation of occupational health and safety measures and means [1-4].

The effective solution of the task of objective occupational risk forecasting is determined by the ability to model, within OHSMS, the processes of dynamic and random impact on the employee over time of all identified NF, which is inherent in the real conditions of the system "man – machine – environment" by using existing methods and models [5-13].

The effectiveness of minimizing the impact of these NF is determined by the ability of the OHSMS to maintain an acceptable level of occupational risk in each workplace in any mode of the system "man – machine – environment" (taking into account the random and dynamic characteristics of the NF impact on the employee over time) through occupational health and safety measures and means. This ability is determined by the ability to constantly monitor the parameters of the impact of the NF of system "man – machine – environment" on the employee (throughout the range of identified NF, including "human factor" signs) and to prompt correct of the researched parameters in case of their deviation from the set criteria. Such criteria include, for example, maximum permissible concentrations (levels) of NF, compliance with the requirements of instructions of occupational health and safety, fire, electrical safety, rules of technical operation, scheduled preventive maintenance, maintenance of technical systems and others [5-16].

The task of objective occupational risk forecasting can be solved in the field of application of stochastic models developed within of previous research, which allow to objectively evaluate the level of major occupational dangers (occupational injuries, diseases) taking into account dynamic and random characteristics of impact of NF of system "man – machine – environment" on employee [17,18].

However, the practical implementation of another task (which mainly depends on the level of professional safety of employees) – the effective maintenance of an acceptable level of occupational risk, has certain problems that relate to possibility and regulations for monitoring and correcting the state of system "man – machine – environment" within existing OHSMS [9,15,19]. The fact is that modern OHSMS are built in such a way that the monitoring of the parameters of the NF impact on the employee is not conducted constantly (which is necessary, taking into account the random and dynamic characteristics of the NF impact on the employee over time, during the work shift), but discreetly by relevant services. Accordingly, the correcting of parameters is very inert and subjective, rather than prompt (again, taking into account the random and dynamic characteristics of the impact), which is a prerequisite for the implementation of risks in occupational dangers [14-16]. Due to the constant complication and intensification of technological processes, as well as the instant change in their operation parameters, the existing approach to occupational health and safety management is inefficient and requires the introduction of

relevant modern automated monitoring and correcting systems that are able to provide the necessary functions of constant monitoring of impact parameters and their prompt correcting [10,13,14,16]. But the analysis of scientific research showed that today there are no automated systems with the required properties that would be able to effectively manage the occupational health and safety at the enterprise by constant monitoring and prompt correcting the parameters of the NF impact on the employee of the system "man – machine – environment" [20-24]. Existing automated systems are not occupational health and safety management systems since, firstly, they are aimed only at minimizing a certain range of NF or occupational risks (in contravention of the recommendations of international occupational health and safety standards on the need for comprehensive protection of employees from all possible NF of the system "man – machine – environment"), and, secondly, do not allow (or allow in a very limited format) to constant monitor and prompt correct of the impact of these NF on the employee.

Thus, in the study [20] to minimize occupational risks a multi-tasking and multifunctional automated control system with functions to control the use of working time, notification of deviations from the set standards value and violations of safety rules was developed. As the system is designed to minimize occupational risks associated exclusively with occupational dangers of a psychophysiological nature, its main disadvantage is the inability to minimize other occupational risks, including those related to the impact of the NF of production environment and others on the employee. Another significant disadvantage of the system is limit of its functions: solely monitoring (at certain intervals, ie not constantly) the parameters of the these dangers impact without functions for their prompt correcting. The existing functionality of the system, which is limited to monitoring the parameters of the impact only certain NF on the employee, together with the impossibility of promt correcting, do not allow to provide comprehensive protection of employees and use the system for occupational health and safety manage in enterprises.

Presented in [21] the information management system of comprehensive control of safety of dangerous production facility contains in its structure means of obtaining data of technological process and ecological situation from sectors of dangerous production facility in time. This system allows to prevent possible emergencies at chemically dangerous enterprises by operative application of preventive measures. The principle of its work is to evaluate the actual parameters deviations from the set indicators. The main disadvantages of this system are lack of control over the erroneous actions of employees and their level of occupational health and safety training (inefficiency in minimizing the "human factor" impact); limited application, as the system is intended only for implementation in chemically dangerous enterprises; lack of general control of the production environment state, which is actually conducted only on two indicators (vapor concentration and the level of losses of harmful and dangerous substances that are stored, rotate on the territory of the enterprise); inability to control other dangerous sectors of production, except those where the employee is subject to impact of NF of chemical group, as well as the lack of a function of prompt correcting of research parameters. Limited use of the system only at certain industry enterprises, as well as limited functionality of the system concerning monitoring the parameters of the impact of only a limited range of NF, together with the lack of ability to promt correct these parameters make it impossible to use it for occupational safety management.

Proposed in the study [22] the integrated monitoring system of controlled objects is designed to increase the level of safety of the enterprise by conductig constant chemical and radiation control, as well as ensuring the required level of fire and explosion safety of the enterprise.

The disadvantages of the system are: the ability to solve a very narrow range of issues related solely to monitoring (but not constant) the dangers of impact of chemical and radiation NF (the system is not able to provide constant monitoring throughout the range of existing NF in the system "man – machine – environment") on employee; insufficient controllability (within the system there is no possibility to promt correct the controlled parameters); lack of control over erroneous actions of employees, especially in dangerous production areas. The limited functionality of the NF monitoring system and the lack of promt correction do not allow the use of the presented system for occupational health and safety manage at enterprises.

Developed in [23] the automated emergency protection system of mines can be used to control the state and status of the production process, both in mining and in other industries, which are characterized by a dangerous technological environment. The introduction of this system allows to promt monitor of the technological process, controlling the safety parameters and the state of the production environment; to identify the danger, in the beginning stages of occurrence, and to stop promptly its

development; to forecast the emergency at the facility. The disadvantages of this system are: limited functionality for constant monitoring and prompt correcting of impact parameters on employee throughout the range of identified NF of the system "man – machine – environment", including sanitary parameters of the production environment, the "human factor" sign, etc. (the system can not provide comprehensive protection of employees); lack of possibility to introduce operative and effective safety measures in case of emergency. These disadvantages do not allow it to be considered for use as a health and safety management system.

The system of early detection of emergencies [24] allows to continuous monitor of actual values of potentially dangerous technological parameters. In the automatic mode it provides prompt response of the relevant services of the enterprise, as well as government agencies with different threat levels (or occurrence) of emergencies. The disadvantages of the system are: lack of universality (the system is aimed at solving a narrow range of issues related only to chemical contamination of the area or facilities); impossibility of automatic elimination of the causes or threat of an emergency (within system only data collection, their processing and the reporting deviations from the set standard values in the absence of functions of promt correcting of research parameters is conducted); lack of control over erroneous employees's actions, which could be a direct or indirect cause of the emergency. Thus, the inability to constant monitor the impact parameters on the employee throughout the range of NF and the inability to promt correct such parameters make it impossible to use this system for occupational health and safety management (comprehensive protection of employees within the systems "man – machine – environment").

The automated systems presented in the following works [25-29], given the focus on minimizing only certain occupational risks or the impact of certain NF, as well as limited or lack of functions for constant monitoring and prompt correcting of such impact also can not be used for occupational health and safety management, since it is not able to provide comprehensive protection of employees from the impact of all identified NF of the system "man – machine – environment".

Thus, the study [25] presents a system aimed at constant monitoring and prompt correcting of only one occupational danger, which is associated solely with the impact of one NF (SF6 gas) on the employee, while other dangers the system can not minimize. The same disadvantage is inherent in the system developed in the study [26]. In this case, the system is designed only to minimize the impact of NF, which is associated with static load on the employee during work (created exclusively for a group of office employees).

The automated system developed in work [27] is intended exclusively for monitoring (telemonitoring) of industrial equipment and facilities. The system controls the state of operation of the equipment, but its functions are purely informational (information collection), while the system does not provide the functions of promt correcting in the event of a dangerous situation for employees. Also, the system does not control other NF, that are associated with, for example, sanitary working conditions, etc.

The system developed in the work [28] is aimed at minimizing occupational danger associated only with the "human factor" signs (including using compliance with the regime of personal protective equipment by employees), as well as (partially) can be applied to dangers associated with the safety of intrashop vehicles (if it is in CCTV cameras view). At the same time, the system does not control and does not provide promt protection of employees from the impacts of other dangers and NF of the system "man – machine – environment" (microclimatic indicators, noise level, vibration level, clean air of the work area and others).

The system presented in work [29] is aimed at monitoring and correcting only one occupational danger associated with the impact of a particular group of harmful substances in the air of the work area (gases) on the employee. At the same time, the system cannot provide an acceptable level of occupational risk throughout the another range of NF (temperature, relative humidity, psycho-physiological factors, etc.) encountered always in the "man – machine – environment" systems.

Given the disadvantages identified during the analysis, which are inherent in existing automated systems, which do not allow them to be used as occupational health and safety management systems at enterprises, institutions and organizations (according to the recommendations of international regulations on occupational health and safety), as well as impossibility (limited) providing constant monitoring and prompt correcting of the parameters of NF impact on the employee within the traditional OHSMS, there is an urgent scientific problem of developing an automated occupational safety management system that would be able to provide appropriate functions and integrate into traditional OHSMS.

To solve a defined urgent scientific problem, within this study, the task is development of system of automated

occupational health and safety management (SAOHSM) to provide comprehensive protection of employees from the negative impacts of NF, which is observed during the functioning of system "man – machine – environment" by constant monitoring of parameters of such impact and their promt correcting.

2. Materials and methods

The following set of research methods was used in the study. Analysis of normative-legal documents and scientific-technical literature in the field of building and functioning of occupational safety and health management systems – to establish a scientific problem statement and research tasks.

Methods of system analysis – to build the overall SAOHSM structure and to establish relationships between its elements (sensors, actuators, etc.), as well as to determine the parameters and criteria for their operation.

Simulation methods, namely discrete-event simulation (DES) of stochastic and dynamic processes – to develop the algorithms of operation and interaction of sensors and actuators: which are responsible for maintaining standardized sanitary and hygienic indicators of the working area (microclimatic indicators, indicators of industrial lighting, industrial noise, content of harmful substances in the air of the working area); which protect employees in emergency situations (prompt access to personal protective equipment, prompt warning of evacuation, etc.); which promt protect employees working in dangerous areas (in particular activation of pyrocartridge of safety screen) and ensure the safety movement of intrashop vehicles. And also discrete-event simulation of deterministic process of management of rational modes of work and rest of employees – to develop the algorithms of operation and interaction of the multipurpose time relay, sensors and actuators of the corresponding subsystem. Methods of decision theory and data mining – to identify and classify violations of the occupational health and safety rules and regulations by each employee during professional activities, as well as to design the individual training programme for employees (taking into account violations) and automated control of occupational health and safety knowledge level during access to the workplace.

3. Results and discussion

The task of creating a system which can increase the efficiency of OHSMS and provide comprehensive protection of employees against occupational dangers impact from identified dangers in the enterprise by connecting functionally independent elements according to a certain scheme was based. Namely, from the NF technical system, the production environment, as well as man (group of people) by minimizing the "human factor" negative signs.

SAOHSM includes the interconnected: employee's personal computer installed in the workplace in the administrative building of the enterprise; the multipurpose time relay (hereinafter the time relay); employee's body position sensor; massage devices with vibration function, placed in the work chair of an employee of the administrative staff; sensors of temperature, relative air humidity, air speed, level of lighting of a working area surface, level of industrial noise; the analyzer of harmful substances in air of a working area; laser emitters installed in dangerous areas of production equipment; sensors of deformation of load-bearing structures of buildings and facilities, as well as deformation of vibration units of technological equipment; electronic terminal installed at the gate of the enterprise; electronic terminals installed in workplaces; CCTV cameras to observe the technological process; GPS sensors installed in the intrashop vehicles of the enterprise; normalizing converters; microprocessor control device; personal computer of the duty operator of the occupational health and safety service; signal amplifiers; light and sound signaling devices; devices to block the production equipment and intrashop vehicles; loudspeaker located in the production area; air conditioning; humidifier and dehumidifier; lighting appliances; filters and dampers of the filter-ventilation system; pyrocartridges; box with electric locking device.

The number of employees' computers, the time relays, work chairs, control sensors, laser emitters, actuating devices, CCTV cameras, GPS sensors, workplace terminals may vary (increase/decrease) depending on the number of workplaces, as well as dangerous areas, which require control. SAOHSM aims to solve the following tasks:

1) Promt data collection concerning the dynamics of changes in the parameters of the system "man – machine – environment" to increase the objectivity of the results of the general occupational risks evaluation, as well as the efficiency of medical examinations and development of treatment and prevention measures.
2) Maintenance of the necessary controlled parameters (intensities of NF emissions in the working area by production equipment) within the limits determined by the results of occupational risk evaluation (see [17,18]).

3) Minimization of negative signs of "human" and certain external factors (state control of the load-bearing structures of buildings and facilities, in case of negative impact on them of earthquakes or other dangerous phenomena of natural or technogenic nature).
4) Prevention of occupational dangers associated with the interaction between NFs. This is achieved through monitoring by the developed system and minimizing the maximum range and relationships of potential NFs. It is known that the interaction between NFs significantly increases the implementation degree of occupational dangers and leads to emergencies [7,16,30,31]. This is due to the strengthening of certain NFs in the presence of others and the creation of an uncontrolled chain reaction with negative consequences [30-32]. These factors are characterized by random occurrence in time, as well as the creation of a large number of combinations between them and, accordingly, negative impacts [16,30,31]. It is impossible to forecast such combinations and impacts using existing safety measures and means. It should be noted that the existing (analyzed) automated systems are only able to minimize (eliminate) the dangers of particular NFs, not their combinations.Thus, they can be eliminated only using the developed SAOHSM system. At the moment, the existence of systems with similar properties is not known, making it a unique.
5) Ensuring the prompt safety of employees from the impact of such NF like flying parts of production equipment or materials. The existence of systems with similar properties is not known currently.
6) Increasing the safety level of employees in emergencies. Due to the combination of components, in case of emergency, the system promptly informs the employee of its occurrence and immediately provides access to personal protective equipment, selected for each workplace, taking into account the anthropometric parameters of employees.
7) Collection and processing data on exceeding the maximum permissible concentrations (levels) for each NF in the continuous monitoring mode. This property is possible due to the special combination of the system components.
8) Reducing the number of industrial injuries and occupational diseases for organizational, psycho-physiological and technical reasons, due to promt comprehensive monitoring of all sources of occupational dangers at the enterprise.
9) Improving the control over the learning and training of employee of occupational health and safety service.
10) Improving the certification of workplaces and reducing the enterprise's costs of its conducting.
11) Conducting promt video surveillance of workplaces with dangerous and harmful working conditions, as well as those ones, whose modes and work results depend on the impact of stochastic factors ("human", external factors, etc.).
12) Management of the rational modes of work and rest set at the enterprise.
13) Improving the economic efficiency of enterprises by increasing the level of productivity, reducing the number of social insurance payments.
14) Improving the level of movement safety and operation of intrashop vehicles.
15) Improving the accounting system and the procedure for investigating occupational accidents, etc.

The schematic diagram of SAOHSM is shown in Figure 1.

Listed in Figure 1 system elements are interconnected in that order. Time relay 2, employee's body position sensor 3, analyzer of harmful substances in the air of the working area 5, temperature sensor 6, industrial noise level sensor 7, relative air humidity sensor 8, lighting level sensor of the working area surface 9, air speed sensor 10, laser emitters 11, 12, sensor of deformation of load-bearing structures of buildings and facilities 13, sensor of deformation of vibration units of technological equipment 14 are connected to the corresponding normalizing converters 16, 18, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29. Each of the normalizing converters is connected to the microprocessor control device (MCD) 38.

Electronic terminal installed at the gate of the enterprise 30, electronic terminals installed in workplaces 31, 32, CCTV cameras to observe the technological process 33, 34, GPS sensors 35, 36 are connected to the personal computer of the duty operator of the occupational health and safety service 37. In turn, the personal computer 37 is connected to the MCD 38. MCD 38 is connected to the personal computer 1 and through the corresponding signal amplifiers 17, 19, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, 62, 63, 64, 65, 66, 67, 68, 69, 70 is connected to time relay 2, massage devices with vibration function 4, filters 71 and dampers 76 of the filter-ventilation system, air conditioner 72, humidifier and dehumidifier 74, lighting appliances 75, pyrocartridges 80, 83, devices to block the production equipment 78, 87, devices to block

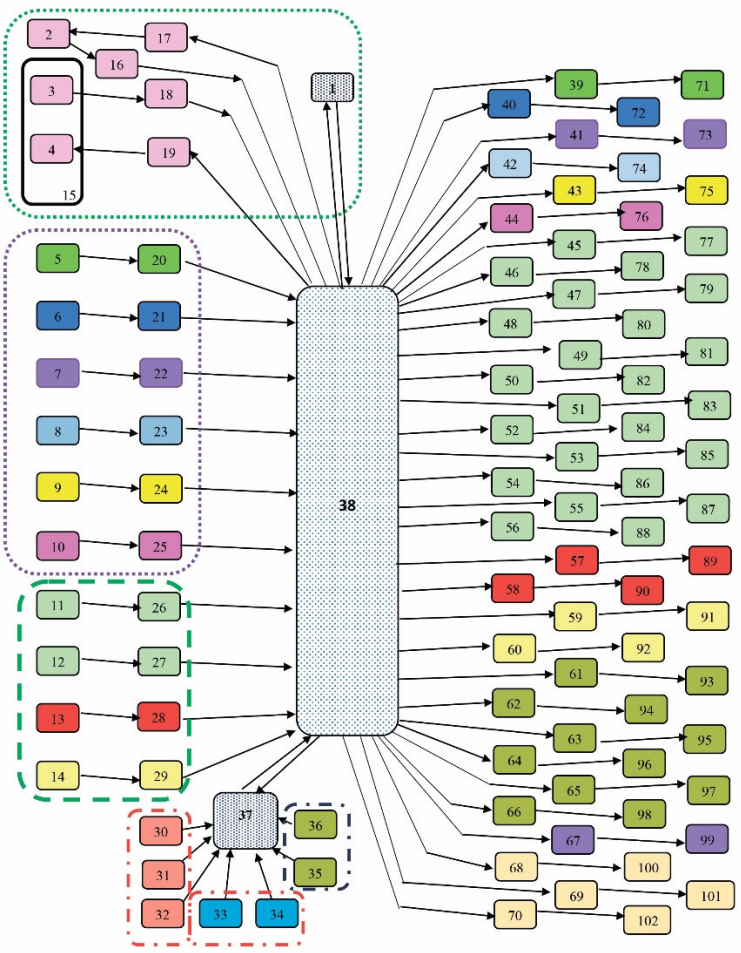

Fig. 1. Schematic diagram of SAOHSM: 1 – personal computer of the employee; 2 – multipurpose time relay; 3 – employee's body position sensor; 4 – massage devices with vibration function; 5 – analyzer of harmful substances in the air of the working area; 6 – temperature sensor; 7 – industrial noise level sensor; 8 – relative air humidity sensor; 9 – lighting level sensor of the working area surface; 10 – air speed sensor; 11, 12 – laser emitters; 13 – sensor of deformation of load-bearing structures of buildings and facilities; 14 – sensor of deformation of vibration units of technological equipment; 15 – work chair of the employee; 17, 19, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, 62, 63, 64, 65, 66, 67, 68, 69, 70 – signal amplifiers; 16, 18, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29 – normalizing converters; 30 – electronic terminal installed at the gate of the enterprise; 31, 32 – electronic terminals installed in workplaces; 33, 34 – CCTV cameras to observe the technological process; 35, 36 – GPS sensors installed in the intrashop vehicles of the enterprise; 38 – microprocessor control device (MCD); 37 – personal computer of the duty operator of the occupational health and safety service; 71 – filters of filter-ventilation system; 72 – air conditioning; 73, 79, 82, 85, 88, 90, 92, 95, 98, 102 – light and sound signaling devices at duty operator of the occupational health and safety service; 74 – humidifier and dehumidifier; 75 – lighting appliances; 76 – dampers of the filter-ventilation system; 77, 81, 84, 86, 101 - light and sound signaling devices at workplaces; 78, 87 – devices to block the production equipment; 80, 83 – pyrocartridges; 89 – light and sound signaling device, which reports the existence of deformation of the load-bearing structures of buildings and facilities installed in dangerous area of workplace; 91 – light and sound signaling device, which reports the existence of deformation of vibration units of technological equipment installed in working area; 93, 96 – light and sound signaling devices on intrashop vehicles; 94, 97 – devices to block intrashop vehicles; 99 – loudspeaker located in the production area; 100 – box with electric locking device, which contains a set of personal protective equipment;

------ Subsystem of compliance of rational modes of work and rest; ------- Subsystem of ensuring of standardized sanitary and hygienic indicators; – – – – Subsystem of promt protection of employees in dangerous areas; – · – · Subsystem of prevention of negative signs of the "human factor"; – · – · Subsystem of ensuring of safety movement of intrashop vehicles

intrashop vehicles 94, 97, light and sound signaling devices at workplaces 77, 81, 84, 86, 89, 91, 101, light and sound signaling devices at workplace of the duty operator of the occupational health and safety service 73, 79, 82, 85, 88, 90, 92, 95, 98, 102, loudspeaker 99 and the box with an electric locking device 100.

Massage devices with the vibration function 4 are placed on the work chair 15 in the lining to the neck, waist, buttocks and thighs of the employee. They are switched on or off according to the developed algorithm. The algorithm of operation of massage devices with vibration function is developed according to the conclusions and recommendations of scheduled medical examinations for each employee separately, taking into account possible health status deviations and features of static loads on employee arising during work. The employee's body position sensor 3 is also placed on the work chair 15 in the lining to the buttocks of the employee. Analyzer of harmful substances in the air of the working area 5 and sensors 6, 7, 8, 9, 10 are installed in the administrative, production, storage and other facilities of the enterprise, which provide workplaces.

SAOHSM works as follows. The signal from the personal computer 1 (when it is switched on at the beginning of the work shift) is sent to the MCD 38, processed and through the signal amplifier 17 transmitted to time relay 2. At the same time, time relay 2 begins the working countdown to rest (according to set the modes of work and rest) for the employee from the workplace. Upon reaching the set rest time, the time relay 2 through the normalizing converter 16 transmits the signal to the MCD 38, which is processed and transmited to the personal computer 1. At the same time, warning information about the beginning of the rest mode and the recommended occupational gymnastics is displayed on the computer screen 1. At the end of the set time required for learning of information and saving working data on the computer 1 by the employee, the time relay 2 through the normalizing converter 16 transmits a signal to the MCD 38 to lock the computer 1 for rest and switch on massage devices 4. Simultaneously, the MCD 38 processes signals from the body position sensor 3, which detect the employee's presence in the chair 15. If the employee is not in the chair, the massage devices 4 are not switched on. At the end of the set massage time, the time relay 2 through the normalizing converter 16 transmits a signal to the MCD 38 to switch off the massage devices 4. After switching off the massage devices 4, the employee leaves the work chair 15; the employee's body position sensors 3 detect this. In this case, the signal from the sensors 3 through the normalizing converter 18 is sent to the MCD 38 and through the signal amplifier 17 transmitted to the time relay 2. The time relay 2 begins the countdown for perform the recommended occupational gymnastics by the employee (according to the set modes of work and rest). At the end of the set time of the rest mode, the time relay 2 through the normalizing converter 16 transmits a signal to the MCD 38 to unlock the computer 1 and begins countdown to the next rest. The relevant information is transmitted to the personal computer of the duty operator of the occupational health and safety service 37 in order to collect and process statistical data for the general production database on occupational health and safety. At the end of the work shift, the employee switchs off the computer 1, thereby transmitting a signal to the MCD 38, which in turn through the signal amplifier 17 switchs off the time relay 2.

Signals from analyzer of harmful substances in the air of the working area 5 and sensors 6, 7, 8, 9, 10 through the normalizing converters 20, 21, 22, 23, 24, 25 are sent to the MCD 38, processed and through signal amplifiers, such as 39, or all 39 - 44 close / open contactor groups, for example, filters of filter-ventilation system 71, or filters of filter ventilation system 71, air conditioner 72, light and sound signaling devices at duty operator of the occupational health and safety service 73, humidifier and dehumidifier 74, lighting appliances 75, dampers of filter-ventilation system 76, thus switching it on or off, or all 71-76.

If the industrial noise level sensor 7 detects the exceeding of the standard value of the controlled indicator, the corresponding signal is transmitted through normalizing converter 22 to the MCD 38, from which it is transmitted to the personal computer of the duty operator of the occupational health and safety service 37 and through the signal amplifier 41 transmitted to the light and sound signaling device 73. At the same time in the production facility, the information for employees about the need to put on the personal protective equipment to hearing sounds through the loudspeaker 99.

The system constantly compares the parameters obtained from the sensors 6, 7, 8, 9, 10 and the analyzer of harmful substances in the air of the working area 5 with the set standard values and, in case of deviation from them, switchs on / off the corresponding actuators. Namely: filters of filter-ventilation system 71; air conditioner 72; light and sound signaling devices at duty operator of the occupational health and safety service 73; humidifier and dehumidifier 74; lighting appliances 75; dampers of the filter-ventilation

system 76. The exceedance value of the indicator (or several indicators), the time during which the value of the indicator was higher than the set (maximum permissible) are detected, processed by the system and recorded online into the general production database on occupational health and safety.

Signals about the interruption of the laser beam "a" from the laser emitters 11, 12, which are installed in dangerous areas of production equipment, through the normalizing converters 26, 27 are sent to the MCD 38, processed and through signal amplifiers, such as 45, 46, 47 or 45 - 47, 54-56 close/open the contactor groups of the light and sound signaling devices, for example, 77, 79 or 77, 79, 86, 88, the devices to block the production equipment, for example, 78 or 78, 87, thus switching them on / off.

Signals about the interruption of the laser beam "b" from the laser emitters 11, 12 through the normalizing converters 26, 27 are sent to the MCD 38, processed and through the signal amplifiers, for example, 48, 49, 50, or 48-50, 51-53 close/open the contactor groups of pyrocartridges, for example, 80 or 80, 83, light and sound signaling devices, for example, 81, 82, or 81, 82, 84, 85, thus switching them on/off. When the corresponding signal on the pyrocartridge 80 and/or 83 is reported, the elastic, clear safety screen between the equipment and the employee are ejected from him/them.

Signals from the deformation sensor 13 as well as the deformation sensor 14, which withstand (or can withstand) dynamic load through the normalizing converters 28, 29 are sent to the MCD 38, processed and through signal amplifiers, such as 57, 58 or all 57-60 close/open the contactor groups of the light and sound signaling devices, for example 89, 90, or all 89-92, thus switching them on/off. If signals are sent to the MCD 38 from the analyzer of harmful substances 5 and sensors 6, 7, 8, 9, 10, 13, 14 through the normalizing converter 20, 21, 22, 23, 24, 25, 28, 29 about the simultaneous sudden total deviation of the controlled parameters from the set (standard) values, the MCD 38 through the signal amplifier 68 opens the contactor groups of the electric locking device of the box 100, which contains the set of personal protective equipment and through the signal amplifiers 69, 70 closes the contactor groups of light signaling devices 101 and 102, respectively, informing about the need to use personal protective equipment and evacuation. The set of personal protective equipment is selected for each workplace, taking into account the anthropometric parameters of employees. The sudden total deviation of the controlled parameters is considered by the system as a dangerous situation or a situation by dangerous consequences. Because NFs, whose change is controlled with analyzer of harmful substances 5 and sensors 6, 7, 8, 9, 10, 13, 14, have the ability to enhance the negative effect of each other.

Graphs of changes in the controlled parameters (information from sensors 3, 6, 7, 8, 9, 10, massage devices with vibration function 4 and analyzer of harmful substances 5) are recorded into the general production database on occupational health and safety and the access to them have except employees of the occupational health and safety service of the enterprise, also medics monitoring the health of employees of enterprise (doctor of the medical institution to which the enterprise is assigned), as well as the accounting department and personnel department.

The occupational health and safety service uses this information to: develop the necessary measures and means to eliminate the identified potential NF and the consequences of their impact; occupational risk evaluation; corrective measures for occupational risk management in the enterprise.

The medics, analyzing the obtained information: determines the degree of negative impact of NF on the employee for each workplace (based on the value of exceeding the standard indicators, as well as the time, during which the employee was influenced by potential NF, etc.); develops treatment and prevention measures for each employee.

The accounting department uses analytical medical reports to determine the amount of employees' compensation for work under dangerous conditions for each workplace.

Each employee of the enterprise has own personal keycard, which contains an n-digit id code, allowing to read owner data from the general production database on occupational health and safety. The personal keycard is used as a pass for entry in the enterprise through the electronic terminal 30 and as an electronic key to the production equipment at the employee's workplace through the electronic terminals 31, 32.

Information from CCTV cameras 33, 34, which are installed in dangerous areas of production facilities or in workplaces with a high risk of negative signs of the "human factor" is transmitted online to the personal computer of the duty operator of the occupational health and safety service 37. The operator monitors the process and gives manually the signals to the light and sound signaling devices 77, 81, 84, 86 through signal amplifiers 45, 49, 52, 54, if the employee's action is incompatible with the occupational

health and safety instructions, fire safety and other safety requirements (safety criteria), or in case of failure of light and sound signaling devices 77, 79, 81, 82, 84, 85, 86, 88 (or one of them) and devices (device) 78, 87.

A certain amount of penalty points are given to the employee on the basis of each violation of safety rules. The sum of penalty points, information on the employee's violation of occupational health and safety instructions during the work experience, information on the induction and special occupational health and safety training, as well as the results of knowledge tests (after training and daily induction, conducted before work beginning through terminals on workplaces), time frame for scheduled medical examinations, as well as regulated modes of work and rest, taking into account working conditions, are recorded into the general production database on occupational health and safety, which is accessed from the personal computer of the duty operator of the occupational health and safety service 37.

Data from the general production database on occupational health and safety are used to: obtain the access to the enterprise (through the electronic terminal 30) and to work (verification is through electronic terminals 31, 32); attestation of employees, taking into account the violations of occupational health and safety requirements recorded by the system, committed by employee during work experience; development of individual modules for occupational health and safety training and induction of employees. Materials from the general production database on occupational health and safety can also be used for statistics and investigation of accidents at work.

Information about the movement of intrashop vehicles from GPS sensors 35, 36 is transmitted online to the personal computer of the duty operator of the occupational health and safety service 37. In case of set safe route deviation, the signal is given automatically through signal amplifiers 61, 62, 63, 64, 65, 66 to the light and sound signaling devices 93, 95, 96, 98 and to the devices to block intrashop vehicles 94, 97.

There is an interaction between MCD 38 simultaneously with the processing of signals and the personal computer of the duty operator of the occupational health and safety service 37 through the interface, namely:

- information on the modes of the personal computer of the employee, time relay, sensors, analyzer of harmful substances, CCTV cameras, laser emitters, GPS sensors, electronic terminals, actuators, light and sound signaling devices, devices to block the production equipment and intrashop vehicles, loudspeaker is processed and presented in graphical form;
- commands concerning the mode change of operation of the time relay, sensors, analyzer, CCTV cameras, laser emitters, GPS sensors, electronic terminals, actuators, light and sound signaling devices, devices to block the production equipment and intrashop vehicles, loudspeaker are sent;
- information on the controlled parameters change is processed and presented in graphical form;
- information on measures and means aimed at eliminating (minimizing) the detected NF, as well as the negative consequences of their impact is displayed;
- images from CCTV cameras are transmitted;
- images from CCTV cameras fixing the intrusion of the employee into the danger area or the flying parts of production equipment or materials (upon receipt of the appropriate signal from the laser emitter) are displayed on the monitor;
- the set safe and real (sent from GPS sensors) route of movement of intrashop vehicles is displayed;
- information on the work beginning of the employee of the administrative group, developed to him modes of work and rest, as well as the recommended set of exercises for industrial gymnastics is displayed;
- information on violations of occupational health and safety requirements, sum of points, the necessity of training and testing of employees, medical examinations, etc. is processed and recorded into the general production database;
- individual training modules, taking into account the violation circumstances, the identity of the employee (experience, qualifications), previous violations are promptly formed (on the basis of the information recorded in the database).

The system constantly monitors:

- sanitary and hygienic indicators in production facilities;
- observance of rational modes of work and rest by employees;
- dangerous areas at workplaces and in production facilities;
- the state of the load-bearing structures of buildings and facilities, which are exposed to dynamic (vibrational) load;
- the movement of intrashop vehicles exclusively on the set, safe for employees route and promptly informs about the danger risk.

The developed system operates in the automatic mode, however manual control in case of an emergency situation is also provided. SAOHSM can be implemented both within individual production facilities and in the enterprise as a whole.

It should be noted that the fundamental difference between SAOHSM and existing automated systems, which are aimed at minimizing only certain occupational risks, is to provide comprehensive protection of employees from the NF impact of the system "man – machine – environment" (throughout the range of NF), in accordance with the guidelines of the relevant international legal documents on the occupational health and safety [1-3]. This property is achieved through the use and interconnection, according to a certain scheme, functionally independent elements designed to constant monitoring and prompt correcting of the parameters of the impact on the employee of all identified NF of the system "man – machine – environment" and other functions (according to items 1 to 15 of tasks, which SAOHSM solves). Also, in contrast to existing systems, SAOHSM is universal, namely, it can be implemented at any enterprise, institution and organization, regardless of their industry that together with the above property makes it unique. SAOHSM aims to improve the efficiency of existing occupational health and safety management systems (reduce the number of accidents, occupational diseases, increase the level of culture and productivity) and is designed to integrate into them.

As an approbation of the conducted researches and clarification of efficiency of application of SAOHSM, it was implemented in the occupational health and safety management system of the industrial enterprise "Stalkanat-Silur" (Odessa, Ukraine). SAOHSM efficiency research have been conducted since January 2019 (date of implementation of the system at enterprise). According to the results, SAOHSM has shown its effectiveness compared with the existing (until January 2019) OHSMS of the enterprise on the basic indicators characterizing the state of occupational safety of employees. Thus, from January 2019 to December 2019 compared with the of year 2018 data, the number of accidents, in particular, related to the work of the employee in dangerous areas of production facilities and process equipment, namely, wire rewinding on spools, strands lay, wire-line core lay, wire rope lay, etc. decreased by 33.3% (by 17 cases); the number of accidents related to the operation of intrashop vehicles, in particular, during the transportation of wire to the wire rope section decreased by 40% (by 3 cases). The number of accidents of a psycho-physiological nature (related to the fatigue state of the employee) decreased compared to the previous period by 28.6% (by 2 cases). The number of violations of instructions on occupational health and safety by employees decreased by 63.2% (by 156 cases). According to a joint analysis of the occupational health and safety service and the financial service of the enterprise, in 2019 productivity increased by 5% due to the improvement of sanitary characteristics of the production environment and compliance with rational modes of work and rest at the enterprise. Using SAOHSM, company reduced the number of social insurance payments by 11%, which are associated with partial disability of employees. Due to temporary shutdowns for the period of quarantine measures related to the COVID-19 pandemic, the data for the year 2020 are not provided in this study (as incorrect for comparison).

4. Conclusions

According to the results of the research, a system of automated occupational health and safety management was developed, which consists of the following main independent elements connected according to a certain scheme: time relay; personal computers; body position sensors; massage devices with vibration function, placed in the work chair of an employee; sensors, analyzer of harmful substances and actuators of subsystems of management of sanitary and hygienic indicators of working areas; laser emitters installed in dangerous areas of production equipment; sensors of deformation of load-bearing structures of buildings and facilities, as well as deformation of vibration units of technological equipment; electronic terminals; CCTV cameras to observe the technological process; GPS sensors installed in the intrashop vehicles of the enterprise; normalizing converters; microprocessor control device; signal amplifiers; light and sound signaling devices; devices to block production equipment and intrashop vehicles; loudspeaker; pyrocartridges; box with electric locking device.

The combination of these elements is aimed at improving the efficiency of OHSMS functioning by continuous monitoring of the parameters of the impact of identified negative factors (including "human factor" signs) of system "man – machine – environment" on the employee and prompt correcting of such impact in case deviation of the identified parameters from the set criteria, as well as the implementation of other functions to provide the safety of employees (including improving the processes of control

over training on occupational safety, certification of workplaces, management of rational modes of work and rest, etc.). In turn, this allows: to reduce the number of occupational injuries at the enterprise through the use of control and protection means of dangerous areas of production equipment (in particular, elastic, clear safety screen); to minimize the consequences of emergencies caused by technogenic or external factors through the use of means of NF control and prompt access of employees to personal protective equipment; to reduce the number of occupational diseases and poisonings through the use of means of continuous control and prompt correction of sanitary and hygienic indicators of the production environment; to increase the general occupational safety level by minimizing the "human factor" signs through the use of means of control over dangerous employee's actions during technological operations and the level of occupational health and safety knowledge of employees, as well as, means to increase such knowledge.

The developed SAOHSM was implemented and tested at "Stalkanat-Silur" enterprise (Odessa, Ukraine). The implementation of this system has improved the occupational safety state at the enterprise (including reducing the number of accidents: in dangerous areas of production by 33.3%; related to the operation of intrashop vehicles by 40%; psychophysiological nature by 28.6%, reduce the number of violations of instructions on occupational health and safety by employees by 63.2%), as well as increase the level of productivity by 5% and reduce the number of payments for social insurance cases by 11%.

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