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MINIMIZATION OF THE "HUMAN FACTOR" INFLUENCE IN OCCUPATIONAL HEALTH AND SAFETY

Purpose. Development of conceptual bases of introduction of system approach to minimization of the "human factor" influence in Occupational Health and Safety.

Methodology. Within the research, the following complex of scientific methods was applied: analysis of scientific and technical literature, legal framework in Occupational Health and Safety and quality assurance in higher education; structural analysis – to determine the structure and causes of occupational danger occurrence; graph theory – to determine the main stages of software development for the automated accounting system and control of changes in the legal framework of Ukraine in Occupational Health and Safety; the theory of Markov processes – to determine the main directions of development of science-based rational modes of work and rest; methods of formalization – to develop the principles of construction an automated system for preventing "human factor" influence.

Findings. The analysis of the system of training of future specialists in Occupational Health and Safety is conducted and the main defects of the qualitative and quantitative composition of standards for higher education, which create conditions for negative "human factor" sign occurrence related to a deliberate breach of the normative legal acts in Occupational Health and Safety by an employee, are determined. The results of the analysis determined the main directions of minimization of given signs. The necessity of use of mathematical tools of graph theory is substantiated and the main stages of the software development for the automated accounting system and control of changes to the legal framework of Ukraine in Occupational Health and Safety are determined. Conditions and the basic directions of construction of stochastic models for developing science-based rational modes of work and rest based application of a special subclass of Markov processes – Markov processes with drift – are defined. The principles of construction and main functions of the automated system of the prevention of "human factor" signs that will allow for constant monitoring and operational correction of given signs, as well as control of qualitative and quantitative characteristics of the identified rational modes of work and rest are proposed.

Originality. For the first time, the necessity of introducing a system approach to minimization of "human factor" signs in Occupational Health and Safety in certain directions is substantiated.

Practical value. The obtained results will be used as an analytical basis for the development of theoretical and methodological tools for introduction a system approach to minimization of "human factor" signs in "man – machine – environment" systems.

Keywords: *Occupational Health and Safety, "human factor", legal framework, Markov processes*

Introduction. The most actual direction of improvement of Occupational Health and Safety management system is an introduction of principles of managing risks of occupational dangers occurrence at enterprises, establishments and organizations. The necessity of their introduction is marked by the requirements of Framework Directive No. 89/391/ECC, by Conception of reformation of Occupational Health and Safety management system in Ukraine, as well as by several of other international laws and regulations in Occupational Health and Safety. These principles provide for successive and cyclic implementation of several procedures aimed at preventing occupational dangers occurrence through providing of functioning of proactive worker safety measures. In practical terms preventing occupational dangers occurrence in the "man – machine – environment" systems can be achieved by removal (minimizations) of risk factors during interaction of the man (employee) with a production equipment and environment [1, 2].

According to the obtained results of statistical data analysis concerning the structure and reasons of work accidents and occupational diseases occurrence and also results of research studies by Liberman A. N. and other authors [1, 3], basic risk factor that leads to the occurrence of 75 to 95 % occupational dangers is exactly a "human factor". The cause of it is impossibility of both objective identification of its signs and lack of the present system of measures concerning their objective minimization. This is due to the difficult essence of the "human factor", which results at the level of its three basic components: biological, social and informational [3].

The "Human factor" can be defined, as conscious (unconscious) actions or inaction of a man (employee) that have led to or could lead to accidents occurrence. In contrast, the employee's personal factors and negative factors of the technical system and productive environment can influence the person's actions or inaction of. The basic personal factors can include the following:

- the lack of human consciousness concerning principles of personal and collective safety provision;
- the lack of knowledge in Occupational Health and Safety;
- the lack of a general culture and work culture;
- psycho-physiological features of a person resulting from his/her genotype (psychosomatic reactions, psychological type features and other biological features of the person).

The negative factors of the technical system and productive environment can include certain nomenclature of harmful productive factors (HPF), accumulation of impact of which in humans could lead to the accident occurrence. It is known that such impact is cause of occurrence of the state of fatigue and other undesirable physiological responses of organism which result in certain errors of an employee, which lead to actualization of certain individual or collective danger [4].

Accordingly, the main task on the way to minimization of the "human factor" is development of measures concerning reduction of the negative impact of personal factors and providing of not exceeding of such a level of accumulation of impact of harmful productive factors in the employee's organism, which with a given probability will not result in certain occupational danger occurrence. The latter is possible providing determination of dependences between the parameters of impact of harmful productive factors on an employee and probability of accident occurrence, which, in turn, requires the special mathematical tools for research on the real random dynamic processes.

Taking into account the complexity of the assigned task and the absence of science-based complex measures regarding minimization of the "human factor" in Occupational Health and Safety, its solution requires introduction of system approach in the following areas:

1. Reforming of the training system regarding Occupational Health and Safety for forming the safety priority and increasing the level of knowledge and work culture.

2. Development of automated systems of prevention of the "human factor" signs, which is related to imperfection of the legal and regulatory (informative) provision in Occupational Health and Safety, and also to the psycho-physiological features of an employee.

3. Construction and grounding of stochastic models for determination of dependences between influence on the employee of certain nomenclature of harmful productive factors and probability of danger occurrence (work injury, industrial accident and the like), taking into account random dynamic characteristics of such influence.

Literature review. The issue of minimization of the "human factor" signs was reviewed in the following scientific works [4–9]. However, their analysis revealed the following of **unsolved problems and defects.**

Thus, in O. V. Vorobyova's research on the basis of statistical data analysis it was defined that an inappropriate level of knowledge, abilities and skills of an employee in Occupational Health and Safety (qualifications), low level of motivation, occupational safety culture (personality), and also insufficient level of his/her awareness and responsibility (quality and quantitative descriptions of the regulated the functions) are the main causes of the "human factor" signs in the "man – machine – environment" systems. On the basis of the conducted research studies the integral criterion of "human factor" evaluation that allows estimating quantitatively influence of its signs on safety of productive processes was suggested and the algorithm of management of "human factor" influence on the risk of occupational injury and accidents origin taking into account the specified criterion was developed by the author. It is suggested that this criterion determination and algorithm implementation be conducted exceptionally on the basis of expert methods, and it puts subjective errors in the evaluation and management result. In addition, absence of measures concerning the removal of certain causes of "human factor" signs within research put in doubt efficiency and objectivity of the developed algorithm of management of "human factor" influence.

In the article [4] basic directions of implementation of prevention of occupational injuries, first among which are removals of the personal causes of injuring, i. e. psychological and psycho-physiological, "human factor" signs are identified and considered. It is marked that minimization (removal) of such signs relate to study and constant monitoring of the psycho-physiological state of an employee, professional selection, permanent studies and instructing about Occupational Health and Safety, as well as to stimulation of an employee to safe work. However, efficiency of the specified measures, although necessary, will be low without forming principles of safety priority in the mind of the person during studies in specialized educational establishments. In addition, a nomenclature of suggested measures for minimization of "human factor" signs is obviously insufficient, because it does not take into account the issue of impossibility of implementation of legal document requirements in Occupational Health and Safety by an employee due to low quality of existent relevant legal framework. Also among the basic drawbacks of the research one should note a failure to take into account such an important aspect as development of the science-based work and rest modes for support of the normal psycho-physiological state of an employee in the conditions of permanent negative influence of harmful productive factors on him/her during a work shift.

In research [5] the injury problems at modern productions are considered, psychological classification of causes of occupational dangers occurrence is given, causes of accidents and work injury occurrence related to the "human factor" are divided into three levels: those of an individual, near environment, and society. The objective factors of working environment that provoke dangerous effects and cause the accident occurrence are noted. On the basis of the conducted studies, with the aim of preventing violation of safety, introduction of the measures of organizational and technical character, excluding the possibility of occurrence or conditioning the actualization of dangerous effects are suggested. Namely, it is suggested to deprive an employee of the opportunity to make a choice between the dangerous and safe methods of activity, to strengthen the educational, promotional and training activities aimed at creating a safe behavior. However, given recommendations are of declarative character exceptionally, because the article does not mark how and in what sequence it is necessary to introduce these measures. Also the developed measures do not cover all directions of "human factor" sign and, accordingly, make system approach to its minimization impossible.

In V. A. Ulyanov's study on the basis of statistical data analysis concerning causes of occupational injuries occurrence, and also acts of investigating the accident, it is identified that the "human factor" is the primary cause of all cases of occupational injuries. The author reasonably offers to minimize the "human factor" signs due to implementation of the "conception of enterprise protection against negative influence of the "human factor" on production" developed in the study. It provides for development and introduction of measures only for three directions, namely, correction of terms of implementation of periodic certification of employees regarding Occupational Health and Safety, improvement of the monitoring system of periodic verification of knowledge regarding Occupational Health and Safety and motivation of employees to compliance of rules regarding Occupational Health and Safety. That is, the developed conception is directed at supporting the relevant level of knowledge regarding Occupational Health and Safety for an employee, and also his/her encouragement (financial) for use of this knowledge in practice. In so doing, the initial level of knowledge of all employees is considered, thus, similarly high; it is the major drawback of the conception. In addition, within the conception a number of causes that can influence the occurrence of "human factor" signs in the "man – machine – environment" systems is not taken into account, such as lack of science-based work and rest modes for the employees of corresponding occupations, unconscious non-performance by the employee of requirements of normative legal acts regarding Occupational Health and Safety, and also necessity of introduction of measures concerning prevention of occurrence of "human factor" signs related to a person's genotype features.

In his works, Ben A. P. regards two basic directions of minimization of "human factor" signs in the system of management of marine transport and emphasizes the necessity of complex solution of the problem in decreasing their negative influence. According to the author, complex approach consists in application of the modern informational systems that provide control of the employees' actions and minimize their participation in the management process and in concurrent introduction of the new programs of training of employees. However, the proposed approach cannot be considered complex, because it does not take into account other directions of minimization of "human factor" signs that, in particular, are related to influence of harmful productive factors on the man during work shift, and also to quality of legal framework regulating the order of safe actions of an employee at work within the technological process.

In research [6] on the basis of results of statistical data analysis, it is found that the "human factor" is the main cause of most occupational accidents. The authors suggest developing complex measures concerning minimization of "human factor" signs on the basis of research of influence of factors of work process on the man. Among other measures of minimization, need for a culture of work safety for the employee, positive reaction toward Occupational Health and Safety, active interaction in prevention of risks actualization at work are marked. However, research character is a review by its nature, as directions of solution of certain problems, and also conceptual vision of need for a systems approach of minimization of "human factor" signs are not described by the authors.

In study [7] on the basis of elaboration of results of an employee questionnaire, balance between safety level at work and productivity of work of an employee, within determination of their relationship with the "human factor" signs, is examined. Importance of taking into account of "human factor" at development of measures and ways aimed at the achievement and support of occupation risk not exceeding the accepted level is shown. As recommendations concerning the achievement of acceptable risk level, the authors suggest adapting education regarding Occupational Health and Safety during recruiting and during work experience to the features of employees (work experience, level of education, personal features of employee, and others). However, the provided recommendations are unsystematic and are not based on principles of the complex approach of minimization of all possible "human factor" signs.

In study [8], on the basis of results of analysis of reports on the investigation of railway accidents and disasters, relevance of influence of the "human factor" on the accidents origin is shown. It is noted that a basic factor that provokes the undesirable "human factor" signs at work is a productive environment which is able to influence an employee negatively, decreasing his/her attention, reducing speed of decision-making and others. However, in this regard, need to take into account stochastic characteristics of influence of harmful productive factors on an employee, which is the obligatory condition for providing evaluation objectivity of such influence and for developing measures for their minimization, was ignored by the authors. Agreeing on the need to develop safety measures in this direction, it should be noted that minimizing "human factor" signs only by improving conditions of productive environment is impossible. The issue of minimization of "human factor" signs must be solved comprehensively, taking into account all possible causes that provoke these signs.

In research by Anastácio P. Gonçalves Filho, Camila C. São Mateus, Daniel S. V. Oliveira, Eros G. Andrade, and Milena P. Muniz on the basis of results of statistical data analysis, influence of the "human factor" on the level of fatal occupational injuries is studied and it is noted that this is the "human factor" which is the main cause of occurrence of vast majority of industrial accidents and disasters. According to the authors, safety of modern production (as a difficult social-technical system) can be achieved only due to the system approach, which provides for minimization of the "human factor" primarily. However, directions in which the system approach should be introduced, as well as practical recommendations concerning its introduction are not given within the article.

In study [9], according to the results of using the multimethodical approach, evaluation of the state of European ports' occupational safety and production culture level of their employees is given. Relationship between the education level of employees regarding Occupational Health and Safety, production culture level and "human factor" signs is shown. A necessity of developments of means that aim primarily to increase the education level of employees regarding collective and individual safety is emphasized. Among the basic drawbacks of the research, it is necessary to distinguish absence of particular ways to solve certain problems, as well as lack of attention to the system character of the issue of the "human factor", minimization of signs of which in the "man – machine – environment" systems should include development of complex preventive measures.

The results of the conducted analysis show that the basic lack of existent research studies is focus on development of discrete measures exceptionally and ways aimed to minimization of certain "human factor" signs regarding Occupational Health and Safety, without necessity of introduction of systems approach by development of science-based complex preventive measures on the basis of analysis of all possible causes of "human factor" signs occurrence.

Purpose. The purpose of the study is development of conceptual bases of introduction of the system approach to minimization of "human factor" signs in Occupational Health and Safety.

To achieve the purpose, the following tasks need to be resolved:

- to conduct the analysis of structure of specialists training system in Occupational Health and Safety in higher education institutions and to develop directions concerning its improvement in accordance with principles of forming of priority of safety;
- to substantiate a necessity and to define development phases of software for automated system of accounting and control of changes in legal framework of Ukraine in Occupational Health and Safety on the basis of application of theory of the graphs;
- to define conditions and basic directions of construction of stochastic models for development of the science-based rational work and rest modes at enterprises, establishments and organizations;
- to define principles of construction and basic functions of an automated system of prevention of "human factor" signs.

Results. Personal attributes of an employee, which further reveal themselves in negative influence of "human factor" signs on the safety state in "man – machine – environment" system, are formed at the innate level (genotype) and formed during the acquisition of life experience. A leading role in forming of the life-skills, in terms of living priorities, belongs to society (by an information transfer) in which a man and the system of his/her education and training are located. Thus, as noted by Serykov G. N., the system of education and training is in this case defining because it forms consciousness of the society gradually.

Ericson E. defined that the basic personal features of a person, that determine his/her behavior features further are formed until the age of 20 years old.

In this particular age period, so-called tutors (parents, educators, teachers, academicians of higher education institution, and others like that) have the greatest influence on consciousness of a person. Thus, the most important task in this period is to inculcating principles of safety priority in any aspects of his life in the future specialist.

Such principles should be integrated into educational programs of training of specialists and expressed in the necessity of obtaining relevant permanent competences.

Foundation for principles of safety priority of a man involves standards of preschool and complete general secondary education, as particularly during this period the child and teenager develop, a model of certain behavior in society on the subconscious level, on the basis of understanding and awareness of the impact of dangerous actions and inactivity. The conducted analysis of relevant standards of education showed that although they indicate the necessity of forming a "model of healthy and safety behavior, maintenance of one's own health and health of other people", they lack quantitative and qualitative characteristics of their obtaining, namely a reasonable list and structure of educational disciplines, the number of hours for their study and others. Lack of higher education standards (and, thus, lack of requirements to the necessity of obtaining safety competences) for training teachers of preschool and secondary education, which, by the way, should form principles of safe life in consciousness of children and teenagers, deteriorates the situation.

However, safety competences within preschool and school education are essential, but by their nature and specific features they will always be very generalized, which is natural, because at this preparation stage, a person only begins to get acquainted with a number of potential dangers (natural, social, technogenic) and realize (given the age) mechanisms of their negative influence, as well as measures of protection from them. It is important to note that according to the conclusions of specialists of the International Labour Organization which are based on the results of statistical data analysis concerning the accident structure by education level of a traumatized person, forming of general safety competences (on the secondary education level) for providing of acceptable level of risk is insufficient [11].

Thus, after forming of general safety competences, the stage of relevant special competence formation is obligatory which should provide insight into the construction of safety principles in such specific sphere of human activity as the industrial one. An industrial sphere is characterized by the large nomenclature of dangerous and harmful production factors, which have permanent negative influence on an employee, which features generally insidious (non-obvious) character of dangers. In this case, the fundamental feature of difference of general and special safety competences is the fact that within the first group of competences knowledge is formed generally concerning the dangers of obvious character, namely up to awareness of negative influence of all nomenclature of dangerous and a number of harmful production factors, whose effects harm the man instantly. For example, group of chemical, biological harmful factors, and also some physical ones (dust, certain types of radiation and others).

However, much larger nomenclature of other harmful production factors influencing non-obviously negatively is not perceived as a danger by man. These might include, for example, a group of psycho-physiological factors (30 % among all causes of occupational diseases occurrence in the European Union countries), absence (insufficiency) of natural light of working surfaces, microclimate indexes, factors related to the design of the workplace and others [11, 12].

Generally, such factors are inherent to the workplaces of an employee performing intellectual work of certain types and, taking into account the permanent dynamics of the increasing share of such workplaces in population, the problem of awareness of their danger for an employee is increasingly threatening (Fig. 1) [13].

Of prime importance in this context is understanding of consequences of such influence, which do not occur only as certain occupational diseases (over time) but also as erroneous actions of an employee ("human factor" signs), which threaten both individual and collective safety in the "man – machine – environment" systems. The described problem should be resolved within two basic aspects. First of all, the "human factor" signs can be caused by both occurrence of tiredness and other manifestation of negative influence of harmful productive factors on an employee. Secondly, these are an employer's not being aware of the importance of development and introduction of safety measures for employees that are negatively influenced by same nomenclature of harmful productive factors. The topicality of the given issue is emphasized by the results of statistical data analysis concerning the dynamic of increase in the number of accidents among the employees of relevant professions [13] and structure of occupational diseases [14, 15] (Figs. 2, 3).

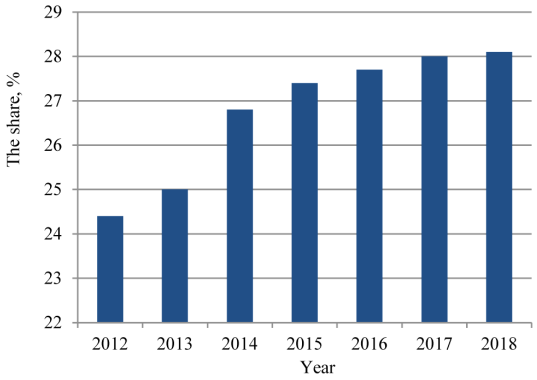
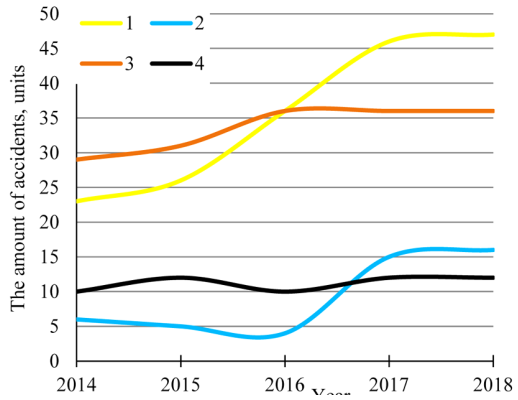


Fig. 1. The share of employees performing intellectual work in employed population of Ukraine



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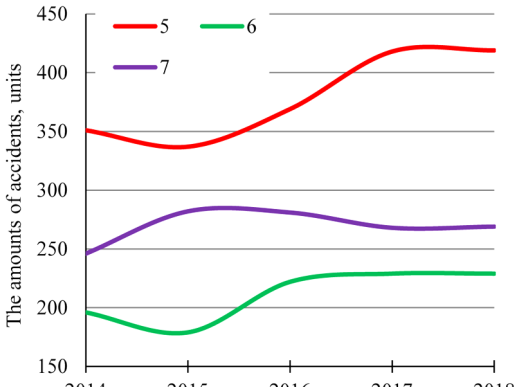

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Fig. 2. Dynamics of changes in the number of accidents by branch of the economy in Ukraine:

a: 1 – financial and insurance activity; 2 – legal activities and accounting; 3 – artistic creation, art and recreational activity; 4 – functioning of libraries, archives, museums operation and other cultural institutions; b: 5 – health and provision of social services; 6 – education; 7 – wholesale and retail trade

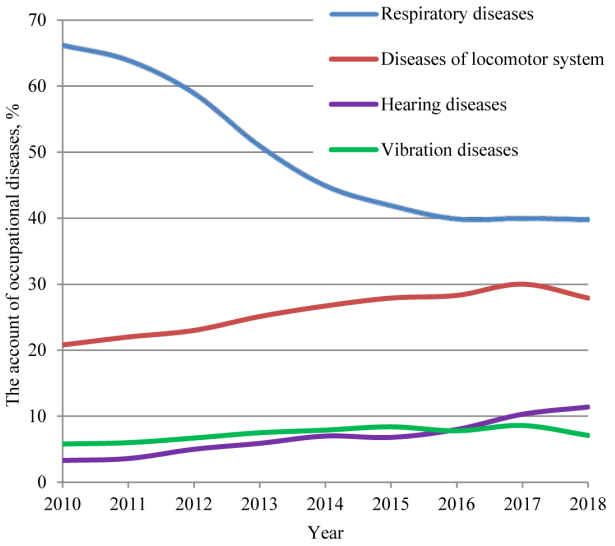

Fig. 3. Dynamics of changes in the structure of occupational diseases in Ukraine

Thus, the important task of the education system is to take into account the two given aspects within special safety competences (in Occupational Health and Safety), especially for the experts of relevant specialities.

In accordance with the current Law of Ukraine "On higher education", competences of future specialists, including those in Occupational Health and Safety (acquiring which is obligatory as required by Article 18 of the Law of Ukraine "On Occupational Health and Safety", in fact) should be represented in the standards of higher education. The given standards are developed by the Scientific Methodological Council of the Ministry of Education and Science by agreement with the National agency on providing higher education quality and they are basis of the modern system of training specialists. However, the conducted analysis on the structure of the existent system under possibility and quality of having competences in Occupational Health and Safety by the future specialists, in accordance with approved standards of higher education by the Ministry of Education and Science of Ukraine, identified follow basic defects [10]:

- lack of standards of higher education for a number of specialities;
- lack of competences relating to Occupational Health and Safety in the list of the approved competences (for most specialities);
- misunderstanding of principles of forming of the number of educational hours for studying disciplines that provide acquisition of competences in Occupational Health and Safety;
- lack of the substantiated list of disciplines forming the given competences.

To date, the standards of higher education have been approved only for 62 from 121 necessary specialities of training of specialists. In the general list of specialities with missing standards of higher education, those ones relating either to the necessity of staff management or to development of intellectual products have the lead. That is, in terms of meeting the requirements in Occupational Health and Safety, relevant specialists should have competences, related not only to protecting of an employee from obvious dangers, but also to protecting from hidden dangers, due to the influence of relevant harmful production factors. Thus, this aspect should be taken into account while designing and developing necessary standards.

However, analysis on the structure of the approved standards showed that only 42 % of them contain a competence that can be only conditionally attributed to acquiring the skills and knowledge in Occupational Health and Safety, namely, "possibility of safe activity" (Fig. 4) [10]. Thus, it is not even the acquisition of the special competences in identification and protecting from such dangers as well as the quantitative and qualitative characteristics of disciplines, which have to provide them.

Regrettably, even such a very general competence is the only one out of 31 recommended ones, those proposed for both the developers of higher education standards and developers of the educational programs in higher education institutions directly. In addition, general nature of the given competence is not only contrary to implementation of directions approved by the order of the Cabinet of Ministers of 12 December 2018, No. 989-p. "Conceptions of reform of system of Occupational Health and Safety management concerning providing its transition to risk-oriented approach (due to impossibility of providing of enterprises by specialists with level of relevant knowledge)", but also provides the basis for determining the number of hours for studying disciplines in Occupational Health and Safety in educational programs and curriculum as a residual.

The thing is, in general, determining the number of hours for studying certain disciplines by student occurs very subjectively, according to recommendations by the Ministry of Education and Science concerning minimum number of credits of ECTS for one discipline (3 credits or 90 hours), which appeared in Letter of Ministry of Education and Science of Ukraine of 13.03.2015, No. 1/9-126. Such an approach is not only incomprehensible but also contributes to incomplete learning by student. When it comes to acquiring the special safety competences, this problem is particularly topical, as it is not just about forming of competences as such but also about the necessity of forming of principles of safety priority for the future specialist.

Forming of such principles should be built exceptionally on science-based foundation which is based on principles of psycho-physiological possibilities of a person concerning assimilation of the information (educational material). In turn, it provides for the necessity of conducting research studies, which will lead to development of models for determination of dependences between complication of material, that should be learnt, and the number of educational hours for such learning. Such models, unlike the well-known methods for determining the number of educational hours, such as expert method or one of proportional distribution taking into account existent data concerning labor intensity measured in hours which are essentially subjective, should be based on objective principles of speed of human analyzers reacting to information, possibilities of its assimilation and conservation during the given period. As a basis for the construction of such models it is appropriate to use well-known psycho-physiological laws such as Veber-Fechner law and others.

In the context of construction of the given models, development and substantiation of nomenclature of disciplines that should guarantee acquisition of all necessary competences concerning provision of individual and collective safety level at work within acceptable values of risk are priority tasks. In this case it is very important to build on the well-known model of

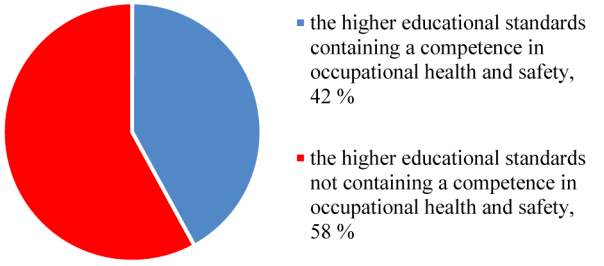

Fig. 4. The share of availability of the special safety competences in the higher education standards in Ukraine

ranging of disciplines of Occupational Health and Safety on the principle from general to special ones (according to currently inactive Order No. 969/922/216 of 21.10.2010). That is, from acquisition of more general competences concerning the nomenclature of all well-known dangers and basic measures and means of protecting from them (for example, within discipline "Vital Activity Security"), graduating to forming of foundation of relating competences in relation to a nomenclature and safety exceptionally from technogenic dangers (for example, within the discipline of "Basics of Occupational Health and Safety") and improving them within disciplines that examine dangers in a certain branch, on the basis of active approach concerning possibilities of managing risks of their occurrence. The latter needs development of a number of special disciplines whose contents relate to training in risks management methods, in accordance with sectors of speciality which trains a future specialist. However, to date, higher educational establishments of Ukraine tend not only to ignore model of ranging of disciplines of Occupational Health and Safety, but also to combine disciplines with the different levels of competences (general and special), and also, in general, excluding them from the educational programs for training specialists. Relevant tendencies are observed in the systems of higher education of countries of the European Union [1].

The issue of science-based approach to forming the number of educational hours and quality features of educational material concerns not only higher education systems. The given problem is topical also for the procedure for training in Occupational Health and Safety, which today is regulated by provisions of the normative legal act in Occupational Health and Safety 0.00–4.12–05 "Typical provisions on procedure of training in Occupational Health and Safety". According to paragraph 2.3 of the Typical provision: "nature and extent of discipline "Occupational Health and Safety" for training, retraining and upgrading qualifications of employees involved into higher risk works, it is determined as a typical training plan and typical training program of the discipline "Occupational Health and Safety" which are approved by the Ministry of Education and Science of Ukraine and are agreed upon by the State Agency of Labour". However, analysis on higher education standards, which replaced typical curricula and training programs according to the Law of Ukraine "On Higher Education", they do not contain any information on the need to study disciplines of Occupational Health and Safety as well as their nature and extent.

Thus, it is determined by the Typical Provision itself that "theoretical part of the discipline "Occupational Health and Safety" is studied for no less than 30 hours, and when retraining and upgrading qualifications – no less than 15 hours. Theoretical part of the discipline "Occupational Health and Safety" during training of employees for performance of activities which are not involved in hazardous work environment, is studied for no less than 10 hours, but when retraining and upgrading qualifications – no less than 8 hours. However, in this case it is unclear from which considerations the number of hours for studying relevant disciplines is defined and what nomenclature and quality of disciplines are meant under the general name of "Occupational Health and Safety".

Thus, the first direction to minimization of "human factor" signs related to influence of an employee's personality factors on safety of the "man – machine – environment" systems is a problem of development of science-based approach concerning provision of quantitative and qualitative characteristics of training in the sphere of Occupational Health and Safety in accordance with forming principles of safety priority in the minds of employees.

Forming principles of safety priority in the minds of employees is aimed primarily at minimization of risks of intentional violation of rules of technological process by them, which is the main cause of accident occurrence according to results of prior research studies. However, it is also determined that such violations can be non-intentional, due to low quality of legal framework of Ukraine in Occupational Health and Safety [1, 3].

The legal framework of Ukraine in Occupational Health and Safety is essentially a guide which sets the rules of safety relationship between an employee and the "man – machine – environments" system. However, lack of the automated accounting of normative legal act and control of their structure changes is a basic drawback, taking into account a lot of nomenclature of documents. Introduction of the automated accounting is necessary not only in connection with a lot of legal framework in Occupational Health and Safety, but also in order to remove duplicate, outdated documents and other drawbacks. Control is needed primarily because normative legal acts of Ukraine in Occupational Health and Safety are related in some way or another and changing (replacing) one document, we should change a number of others simultaneously. The given procedures of accounting and control are to be undertaken within automated system of accounting and control of changes in the legal framework of Ukraine in Occupational Health and Safety developed by the authors [1]. The topicality of its development and introduction at the state level is emphasized, in particular, in provisions of Conception of Reformation of Management System of Occupational Health and Safety in Ukraine.

However, to date, a possibility of the general implementation of the given automated system in the relevant state institutes is limited due to absence of relevant software for it. During development of the necessary software it is important to understand that to change a normative legal document in Occupational Health and Safety (law, resolution, provision and others) is to change one of its articles (paragraphs) at least. While changing an article of a normative legal document, one is to find responsively all articles in all normative legal documents on which this article was based (directly or indirectly) and which are based on this article (directly or indirectly). This formulation of the task prevents the use of simple methods of general search, given a lot of documents (over 10 thousand documents) that need to be processed. To solve such tasks, it is the most convenient to use mathematical tools of graph theory, within which the fact is considered, in particular, that the change in any normative legal documents causes (or may cause) the need for changes in other documents on which it is based and which are based on it. In the latter case, the need to make changes is mandatory.

Thus, in the context of this task, two graphs can be taken into account:

1. A graph whose peaks are all the normative legal documents of Ukraine in Occupational Health and Safety (Fig. 5).

2. A graph whose peaks are all the normative legal documents (NLDs) of Ukraine in Occupational Health and Safety and all their articles (paragraphs) (Fig. 6).

This distribution is necessary for the convenience of constructing the algorithm of the system operation, since all documents are first of all checked in order to determine the group of related ones, which are further processed within the second graph.

The set of peaks of the first graph is a subset of the sets of peaks of the second graph. Both graphs can be viewed as non-oriented as well as oriented. The adjacency matrices that define these graphs are created naturally.

The solution of the task of developing software for the system of automated accounting and control of changes in normative legal documents of Ukraine in Occupational Health and Safety can be divided into the following stages:

1. The definition in this graph of connected subgraphs and then each subgraph is treated as a separate connected graph. It is expected that such separate connected graphs in the absence of orientation, will be trees or forests. One should keep in mind that changing an article (paragraph) of normative legal docu-

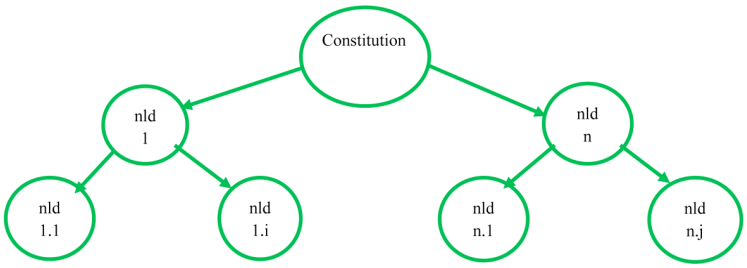

Fig. 5. Conventional representation of a graph whose peaks are only the normative legal documents (NLDs) of Ukraine in Occupational Health and Safety (NLD 1... NLD n; NLD 1.1... NLD n.j), where n, i, j ≥ 2 – any natural number

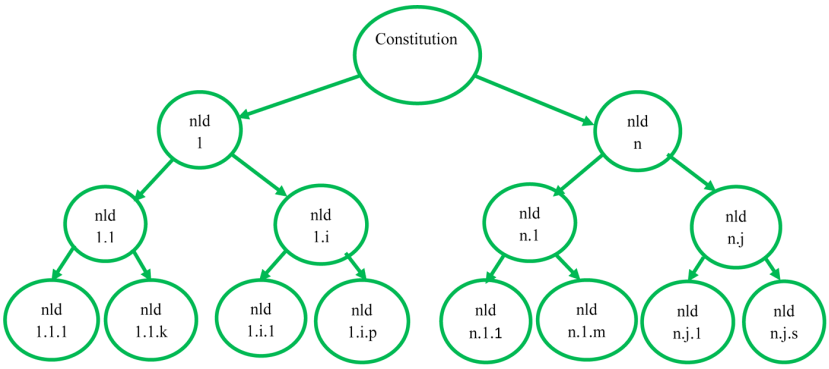

Fig. 6. Conventional representation of a graph whose peaks are all the normative legal documents (NLDs) of Ukraine in Occupational Health and Safety (NLD 1... NLD n; NLD 1.1... NLD n.j) and all their articles (NLD 1.1.1... n.j.s), where n, i, j, k, p, m, s ≥ 2 – any natural number

ments can fundamentally change graphs themselves, which needs to be taken into account.

2. The definitions of all chains (routes) to which given peaks of the graph belongs, with the possible imposition of certain conditions, as well as all of the peaks of graphs belonging to these chains (routes).

Each of the two stages of solving the task can be implemented using standard algorithms.

3. Programming algorithms and creation of convenient software interface. When designing interface, one should take into account that potential users will not be experts in computer technology.

The practical part of implementing the given algorithms is related to the analysis of a lot of text documents, so it is additionally necessary to develop a simple and clear classification (system of identification) of normative legal documents and their articles (paragraphs) related to the existing classification. The purpose of such classification should be to simplify the lexical analysis of the text of normative legal documents in the program implementation of algorithms.

The next direction on the way of providing a system approach to minimizing the negative "human factor" signs in the "man – machine – environment" systems is related to the need to minimize the signs of the "human factor" due to the negative impact on the employee of a certain nomenclature of harmful production factors from production equipment and environment. This effect can cause the employee to experience a state of fatigue and other negative consequences associated with the deterioration of his/her psychophysiological state, which can cause danger occurrence in the "man – machine – environment" systems. This direction of minimizing the "human factor" signs should be considered in the context of the development of science-based methodological support for determining rational modes of work and rest for employees of different professions. The urgency of developing such support is due to the following problems:

- statistical factors concerning dynamics of the increase in the number of accidents related to the state of fatigue;
- emergence and dynamics of an increase, in the developed world, in a fundamentally new occupational danger – mortality from a chronic state of fatigue associated with the performance of professional responsibilities;
- lack of objective, science-based methodological support for the development and implementation of rational modes of work and rest in the workplaces of enterprises, institutions and organizations.

Existing statistics in Ukraine concerning structure of causes of accidents occurrence still do not address separately the causes associated with the state of fatigue, including them in the group of psycho-physiological causes, the dynamics of which shows steady growth. Thus, during the last ten years, accidents due to psycho-physiological causes have consistently been taking the second place among others, showing stable dynamics of growth (Fig. 7) [13, 14].

The urgency of solving the problem of accidents arising from the state of fatigue is emphasized by their share compared to other causes for EU countries, where state of fatigue is considered as a separate cause of relevant accidents. Thus, over the last 10 years, the number of accidents due to the state of fatigue has increased on average by 75 % across the EU countries. However, the analysis of foreign scientific research studies showed that their directions still do not relate to the development of science-based methodological support for implementation of rational modes of work and rest, which are aimed at solving these problems [11, 12].

The lack of science-based modes of work and rest, as well as control over their observance became a cause of a relatively new occupational danger which for the first time drew attention in Japan and is called karosi. Karosi (jap. karo:si) is a fatal incidents with employees from the state of the chronic fatigue associated with the performance of their professional duties (Fig. 8) [16]. Although in many countries, including Ukraine, this problem has drawn very little attention, global trends con-

cerning increasing competition in the labor market, increasing levels of psycho-physiological stress on the employee, the need to perform large amounts of work in the shortest possible time together with the statistical data regarding the constancy of the cases Karosi during of monitoring this danger, indicate the need to develop a system of preventive measures with prevention of such cases. Primarily, these measures should relate to the problems of implementation and compliance of objective modes of work and rest at each workplace [17].

The situation in Ukraine in the context of support of the development and implementation of science-based modes of work and rest in the workplace is not better. To date, the development and implementation of modes of work and rest within enterprises, institutions and organizations is based on the requirements of the Labor Code, State sanitary regulations and standards 3.3.2.007-98 "Hygienic requirements to organization of work with visual display terminals of computers", as well as sectoral normative legal acts for certain professions, namely: Provision on modes of work and rest of employees of professions prone to vibration disease, Recommendations on labour organization of civil servants in Executive Branch. At the same time, State sanitary regulations and standards 3.3.2.007-98 give requirements to modes of work and rest are only for three groups of employees:

- software developers (software engineers);
- operators of computers;
- operators of computerized typesetting.

For other occupational groups of employees, it is suggested that the owner of the enterprise should develop the normative support for implementation of modes of work and rest on the basis of the Labor Code (Articles 66 and 142).

However, the Labor Code contains requirements exclusively concerning the time limits for implementation of lunch breaks and vacations. This document does not contain any other requirements for breaks during work shifts.

The existing approach in the State sanitary regulations and standards 3.3.2.007-98 concerning the development of rational modes of work and rest provides for determination of their qualitative and quantitative (temporal) characteristics. Qualitative characteristics are established based on the work specifics of the employee, which includes static or dynamic stresses on him/her. The mode of active rest is recommended regarding static work and, in contrast, passive one is recommended regarding dynamic work. The complex of exercises,

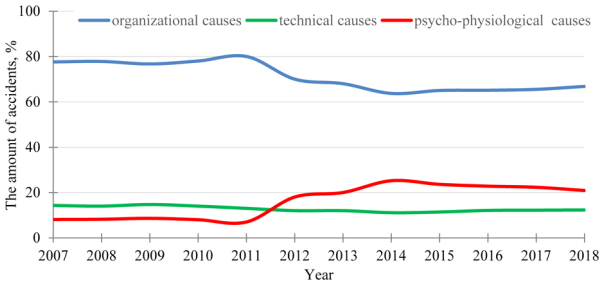

Fig. 7. Dynamics of structural changes in the causes of occupational accidents occurrence in Ukraine

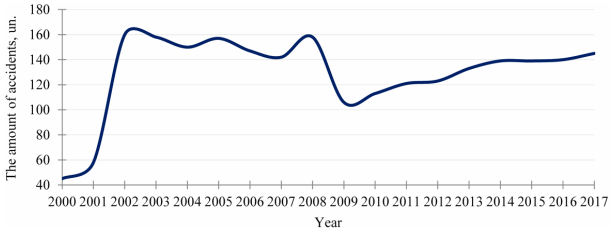

Fig. 8. Dynamics of change in the number of accidents due to Karosi

which, in turn, aims to restore the normal performance of certain analyzers, muscle groups, etc., is also proposed to each mode.

Quantitative characteristics of modes of work and rest are established based on fixed periods during which an employee should work and rest. For example, for employees performing work on a PC such modes within 8 hours' work shift are 2 hours of work and 15 minutes of rest. In this case, the document does not explain why such a time limit is proposed.

It is clear that the establishment of regulated breaks during the work shift aims at restoring the functional characteristics of the employee to prevent the occurrence of a state of fatigue or other negative consequences due to the impact of a certain nomenclature of harmful production factors on the employee. The characteristics of the negative impact of the harmful production factors as well as their nomenclature are specific to each workplace at any particular enterprise. Therefore, it would be reasonable to conclude that the given modes of work and rest should be established taking into account the characteristics of such impacts throughout the nomenclature of the identified harmful production factors. Consideration of the dynamic characteristics of the random impact of such factors on the employee during the work shift and the process of employee's rehabilitation process when there is no such impact is mandatory.

However, to date, there are no methodological approaches that are based on the principles of establishing the necessary modes according to the objective characteristics of such an impact. It is known that modern methods for establishing rational modes of work and rest for employees of certain professions are based on two main approaches: expert and statistical. The first one provides the determination of the so-called fatigue coefficient, which is calculated on the basis of expert evaluations, taking into account working conditions (intensity of work, monotony in the work, pace of work, position of the employee, sanitary and hygienic indicators in the workplace, etc.) [18]. The second one, according to the results of G. B. Leonova's studies, provides for the establishment of modes of work and rest based on the statistical data of studies concerning changes in the functional state of employee in production conditions. The latter approach is more objective, but its implementation to the development of modes of work and rest for each professional group (specialty) requires the use of a large number of resources to processing of large arrays of statistics, which in practice is very difficult or impossible obtained. In addition, the specificity of each workplace at every enterprise, and therefore the specific characteristics of the negative impact of harmful production factors on the employee, cannot be objectively taken into account in this approach, which is its fundamental disadvantage.

Accordingly, the main task of developing objective methodological support for establishing science-based modes of work and rest is to determine the relationship between the accumulation of the impact of harmful production factors in an employee and the probability of a certain danger occurrence due to the consequences of such impact. The task can be reduced to determining such intensities of the impact of the harmful production factors, whose accumulation will not achieve the given (normalized) values in an employee during a work shift. In determining such parameters, it is obligatory to take into account the stochastic characteristics of both the negative impact of the harmful production factors on employee over time and the removal of consequences of such impact from the body during regulated breaks and over hours [19].

The given task, taking into account the need for simultaneous consideration in the random process of both discrete components (the accident occurrence due to the "human factor" signs) and continuous ones (the negative impact of harmful production factors and the derivation of its consequences), can be solved by implementation of special mathematical tools

of the theory of Markov processes (Markov processes with drift). In this case, it can be accepted that the probability of an accident occurrence depends in some way on the current value of the level of accumulation of the negative impact of harmful production factors in an employee. Mathematically, this means that the parameters characterizing the time of impact of harmful production factors λ on an employee and the time of restoration of the body from such impact μ become certain functions of x – the number of harmful substances in the employee's body at time t. Thus, $\lambda_{ik}(x)$ should be an ascending (or non-descending) function and $\mu_{ik}(x)$ should be a non-ascending (or descending) function, where i and k are discrete variables describing the employment and working capacity of the employee at time t, during the work shift, respectively [19].

The development of methodological support for determining the required dependencies will allow the establishment of objective, science-based modes of work and rest for employees of different professions, using as input the parameters that can be instrumentally measured in each workplace.

Finally, the last direction of introduction of a system approach to minimizing the "human factor" in "man – machine – environment" systems is associated with the need to take into account the dangers that may be caused by the actions or inactions of the employee, due to his/her innate psycho-physiological features (genotype), as well as those caused by a random change in work capacity (loss of consciousness, reflex reactions, etc.). Taking into account the stochastic nature of such actions (inactivity) in time and space, there is a need for their constant monitoring and operational correction within "man – machine – environment" systems by implementation of certain automatic tools in workplaces (where the safety in "man – machine – environment" systems depends on actions/inactivity of the employee). Despite the need for implementation of the system approach that requires the minimization of all possible nomenclature of "human factor" signs in "man – machine – environment" systems, the given tools are appropriate to use in the specialized system, the so-called automated system of prevention of "human factor" signs. Therefore, the given system, taking into account the possible nomenclature of "human factor" signs, as well as the need for application of established modes of work and rest by employees in the workplace, should ensure the following tasks:

- continuous monitoring of the level of knowledge of the employee in occupational health and safety in the workplace;

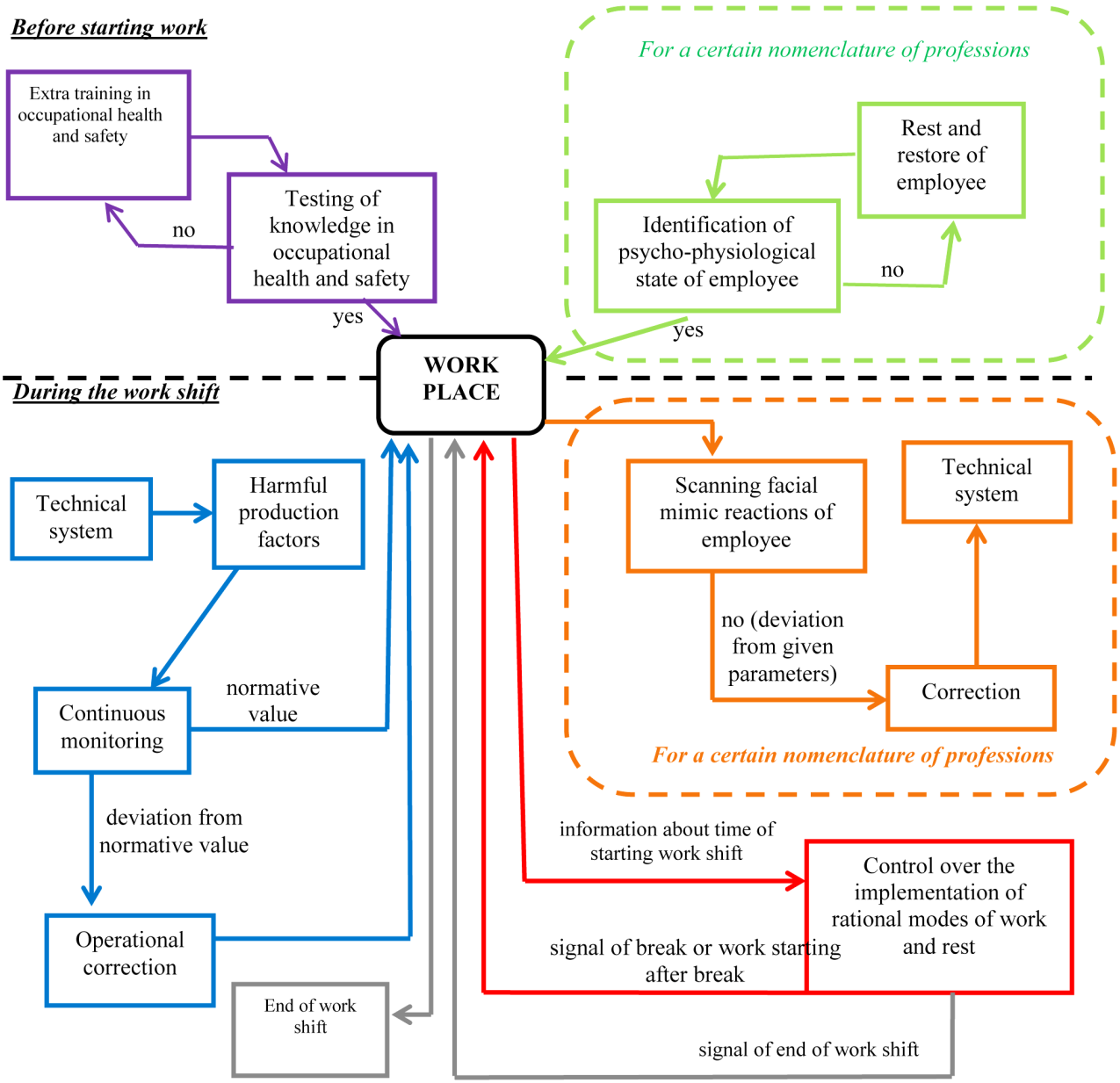

Fig. 9. The schematic of operation of the automated system of prevention of "human factor" signs

- operational correction of the intensity of the negative impact of harmful production factors on the employee;

- constant monitoring and correction of random changes in working capacity of the employee at particularly important workplaces (in terms of implementation of the general safety of employees);

- monitoring of the qualitative and quantitative characteristics of the established rational modes of work and rest.

Accordingly, the functions of an automated system to prevent "human factor" signs are:

1. Operational testing of knowledge in occupational health and safety at workplace (before starting work).

2. Continuous monitoring and operational correction of the parameters of the negative impact of the identified harmful production factors on the employee.

3. Constant control (before starting work) of the psychological state of the employee by testing (for a certain nomenclature of professions).

4. Recognition of the state of working capacity by constantly scanning facial mimic reactions (for a certain nomenclature of professions).

5. Control over the implementation of rational modes of work and rest according to a certain nomenclature of professions.

The general principle of operation of the automated system of prevention of "human factor" signs is shown in Fig. 9.

Conclusions.

1. The analysis of the system of training of future specialists in Occupational Health and Safety identified the following major drawbacks of the qualitative and quantitative composition standards for higher education, which creates conditions for occurrence of negative "human factor" signs related to a deliberate breach of the normative legal act in Occupational Health and Safety by an employee:

- the lack of the requirements for the forming of competences in occupational health and safety in contents of 58 % approved standards for higher education. The given competencies do not exist in the standards of higher education for specialties whose proportion in the labor market is the biggest and has a tendency to grow;

- limitation of nomenclature safety competence in the general list of recommended ones;

- impossibility of forming the principles of priority of safety within the existing competencies and the risk of an indicative approach to the management of occupational health and safety;

- the lack of standards of higher education disciplines that ensure the acquisition of safety skills;

- the lack of a science-based approach to setting the number of training hours required for full acquisition of human safety competencies.

According to the identified defects, the main directions of reforming the system of training of future occupational health specialists are:

- introduction of norms into the provisions of the Law of Ukraine "On Higher Education" regarding the mandatory presence in the contents of higher education standards for each and every specialties, of a certain list of safety competences, aimed at providing employees with a level of individual and collective safety at work within acceptable levels of risk;

- development and substantiation of the nomenclature of disciplines that guarantee acquisition of all the necessary competences, taking into account the principle of their ranking from general to specific;

- development of a mathematical model for determining the dependence between the complexity of the material to be learned and the number of training hours, based on the provisions of known psycho-physiological laws, such as Weber-Fechner and others.

2. The application of the graph theory mathematical tools to the development of software for the automated accounting system and control of changes in the legal framework of Ukraine in occupational health and safety is explained by the need to process a lot of documents (more than 10 thousand documents) that have multiple relationships. Development of given software is necessary in order to minimize the "human factor" signs, which are related to the imperfection of the legal framework of Ukraine in occupational health and safety. The task of developing software can be divided into the following stages:

- the definition in this graph of connected subgraphs for the possibility of considering them as separate;

- the definitions of all chains (routes) to which given peaks of the graph belongs, with the possible imposition of certain conditions, as well as all of the peaks of graphs belonging to these chains (routes);

- programming algorithms and creation of convenient software interface.

3. The task of developing science-based modes of work and rest can be formulated as finding the probable distribution of a random process with parameters describing the change in the state of employment and working capacity of the employee in time, as well as the level of accumulation of the negative impact of harmful production factors in the organism of the employee during regular breaks and during non-business hours. The given task, taking into account the need for simultaneous consideration in the random process of both discrete components and continuous ones, can be solved by implementation of special mathematical tools of the theory of Markov processes (Markov processes with drift).

4. The principle of construction of an automated system for preventing the "human factor" signs is to:

- continuous monitoring of the level of knowledge of the employee in occupational health and safety in the workplace;

- operational correction of the intensity of the negative impact of harmful production factors on the employee;

- constant monitoring and correction of random changes in working capacity of the employee at particularly important workplaces (in terms of implementation of the general safety of employees);

- monitoring of the qualitative and quantitative characteristics of the established rational modes of work and rest.

Accordingly, the general functions are:

- operational testing of knowledge in occupational health and safety at workplace (before starting work);

- continuous monitoring and operational correction of the parameters of the negative impact of the identified harmful production factors on the employee;

- constant control (before starting work) of the psychological state of the employee by testing (for a certain nomenclature of specialties);

- recognition of the state of working capacity by constantly scanning facial mimic reactions (for a certain nomenclature of specialties);

- control over the implementation of rational modes of work and rest according to a certain nomenclature of specialties.

Effective minimization of "human factor" signs in the "man – machine – environment" systems on determined directions taking into account the complexity of the relevant issues is possible only within the systems approach, the introduction of which in the given systems ***is a promising way of research development.***

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Мінімізація впливу „людського фактора“ у сфері охорони праці

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Мета. Розробка концептуальних основ забезпечення системного підходу до мінімізації впливу „людського фактора“ у сфері охорони праці.

Методика. У рамках дослідження застосовувався наступний комплекс наукових методів: аналіз науково-технічної літератури, нормативно-правової бази з охорони праці та забезпечення якості вищої освіти; структурний аналіз – для визначення структури та причин виникнення професійних небезпек; теорія графів – для визначення основних етапів розробки програмного забезпечення автоматизованої системи обліку й контролю змін нормативно-правової бази України з охорони праці; теорія марківських процесів – для визначення основних напрямів розробки науково-обґрунтованих раціональних режимів праці та відпочинку; методи формалізації – для розробки принципів побудови автоматизованої системи запобігання впливу „людського фактора“.

Результати. Проведено аналіз системи підготовки майбутніх фахівців з питань охорони праці й визначені основні недоліки якісного й кількісного складу стандартів вищої освіти, які створюють передумови для виникнення негативних проявів „людського фактора“, що пов'язані з навмисним порушенням працівником вимог нормативно-правових актів з охорони праці. За результатами аналізу визначені основні напрями мінімізації зазначених проявів. Обґрунтована необхідність використання математичного апарату теорії графів і визначені основні етапи розробки програмного забезпечення автоматизованої системи обліку й контролю змін нормативно-правової бази України з охорони праці. Визначені передумови та основні напрями побудови стохастичних моделей для розробки науково-обґрунтованих раціональних режимів праці та відпочинку на основі застосування спеціального підкласу марківських процесів – марківських процесів зі знесенням. Запропоновані принципи побудови та основні функції автоматизованої системи запобігання проявам „людського фактора“, що дозволять здійснювати постійний моніторинг і оперативне корегування зазначених проявів, а також контроль за якісними й кількісними характеристиками встановлених раціональних режимів праці та відпочинку.

Наукова новизна. Уперше обґрунтована необхідність запровадження системного підходу до мінімізації проявів „людського фактора“ у сфері охорони праці за визначеними напрямами.

Практична значимість. Отримані результати будуть використані як аналітична база для розробки теоретико-методологічного інструментарію запровадження системного підходу до мінімізації проявів „людського фактора“ в системах „людина – машина – середовище“.

Ключові слова: *охорона праці, „людський фактор“, нормативно-правова база, марківські процеси*

Минимизации влияния „человеческого фактора“ в сфере охраны труда

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Цель. Разработать концептуальные основы обеспечения системного подхода для минимизации влияния „человеческого фактора“ в сфере охраны труда.

Методика. В рамках исследования применялся следующий комплекс научных методов: анализ научно-технической литературы, нормативно-правовой базы по охране труда и обеспечению качества высшего образования; структурный анализ – для определения структуры и причин возникновения профессиональных опасностей; теория графов – для определения основных этапов разработки программного обеспечения автоматизированной системы учета и контроля изменений нормативно-правовой базы Украины по охране труда; теория марковских процессов – для определения основных направлений разработки научно-обоснованных рациональных режимов труда и отдыха; метод формализации – для разработки принципов построения автоматизированной системы предупреждения влияния „человеческого фактора“.

Результаты. Проанализированы системы подготовки будущих специалистов по вопросам охраны труда и определены основные недостатки качественных и количественных характеристик стандартов высшего образования, создающие предпосылки для возникновения негативных проявлений „человеческого фактора“, связанных с умышленными нарушениями работником требований нормативно-правовых актов по охране труда. Согласно результатам проведенного анализа, определены основные направления для минимизации указанных проявлений. Обоснована необходимость применения математического аппарата теории графов и определены основные этапы разработки программного обеспечения автоматизированной системы учета и контроля изменений нормативно-правовой базы Украины по охране труда. Определены предпосылки и основные направления построения стохастических моделей для разработки научно-обоснованных рациональных режимов труда и отдыха на основе применения специального подкласса марковских процессов – марковских процессов со сносом. Определены принципы построения и основные функции автоматизированной системы предотвращения проявлений „человеческого фактора“, позволяющие осуществлять постоянный мониторинг и оперативную корректировку указанных проявлений, а также контроль за качественными и количественными характеристиками рациональных режимов труда и отдыха.

Научная новизна. Впервые обоснована необходимость внедрения системного подхода для минимизации проявлений „человеческого фактора“ в сфере охраны труда по определенным направлениям.

Практическая значимость. Полученные результаты будут использованы как аналитическая база для разработки теоретико-методологического инструментария внедрения системного подхода для минимизации проявлений „человеческого фактора“ в системах „человек – машина – среда“.

Ключевые слова: *охрана труда, „человеческий фактор“, нормативно-правовая база, марковские процессы*

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