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The Human Factor A Main Tool of Occupational Accidents and Diseases Prevention in Industry

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Abstract.

A new conceptual model of the human factor (DARA model - Difference Actual and Required Abilities) is proposed, in which the human factor is defined as the difference between the actual abilities of a person to perform work and the requirements for the employee's abilities set by the scope of work performed. Examples of changes in the human factor across time and space have been given. Reliability of human factors and accident hazards have been assessed taking into account the professional employment record of an employee. Moreover, a template of impacts at the employer level, according to which additional measures can be introduced into the existing occupational safety and health management systems of various levels to ensure effective management of the human factor have been given.

Keywords: abilities; risks; accident; occupational safety; human factor.

Introduction

The term "human factor" was first time introduced in a book published in 1921, and since that time

English sociologist and industrialist Benjamin Seebohm is considered the author of this term and the initiator of its scientific use. [26]

Scientific researches [4,6,25] around the world have established and constantly demonstrate the importance and relevance of studying the impact of the human factor on the level of occupational risks, the number of accidents and occupational morbidity. This interest is primarily due to the fact that at present, 70-90% of all incidents and accidents are caused by the human factor [6,11,17]. Based on the above percentage, for calculations in this work, the authors had took an average estimate of the human factor impact of 80%.

Below are some of the most common views on the concept of the human factor.

Main Part

According to the International Ergonomics Association (IEA): *Ergonomics (or human factors) is the scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data and methods to design in order to optimize human well-being and overall system performance.[30]*

In the resent edition "Principles and guidelines for human factors/ergonomics (HFE) design and management of work systems" jointly prepared by the International labor Office (ILO) and the International Ergonomics Association (IEA) a new effective human factors and ergonomics system has been developed and described. [29]

The World Health Organization (WHO) in [13] notes the following definition of the human factor: *Human factors refer to environmental, organizational and job factors, and human and individual characteristics which influence behaviour at work in a way which can affect health and safety. A simple way to view human factors is to think about three aspects: the job, the individual and the organization and how they impact on people's health and safety-related behaviour.*

Moreover, while addressing the human factor from a scientific point of view, WHO believes that workplaces should be designed and organized so that human errors and their consequences are minimized. If human errors at work cannot be eliminated, then, it is necessary to control and avoid occupational risks.

In the context of economic globalization, increasing migration flows of the labor force and the constant emergence of new professions and new jobs, social partners in developed and developing countries raise their requirements for working conditions, occupational safety and health of workers. More and more employers now recognize that normal working conditions are the main component of modern production management. Workforce management methods are beginning to pay special attention to working conditions, with focus on identifying, assessing and eliminating occupational risks taking into account the human factor. [16]

The Russian standard [7] gives a slightly different definition of the human factor: "The totality of personal characteristics and behavior of a worker that cause deliberate or unintentional, but incorrect, actions of a different nature in the process of work, ultimately leading to dangerous incidents and situations, disruptive events, accidents, work-related and occupational diseases".

There are other definitions of the human factor [12]: "human factor is a complex multifaceted issue that affects maritime safety and protection of the marine environment. It covers the full range of human activities performed by ship crews, onshore management personnel, regulators, recognized organizations, shipyards, legislators and other relevant parties, all of whom must work together to effectively address human factors issues." As a rule, a negative meaning is put into the concept of the human factor, associated with the employee's mistakes, which lead to incidents, accidents, emergencies and disasters.

In general, we can note that there is no single generally accepted definition of the human factor; depending on the research goals and objectives, individual definitions of the human factor are developed, emphasizing the specifics of these studies.

N. M. Dobrotvorsky [2] was one of the first researchers, who, in 1930, stressed the importance of the human factor in aviation through his research on the human adaptation to technology and technology to HUMANS. This approach was finally formalized by ICAO (International Civil Aviation Organization) by including human factors requirements in the requirements for training aviation personnel based on the conceptual SHEL model [14].

The SHEL model, created by Edwards in 1972, was supplemented in 1975 with Hawkins diagram. SHEL is an abbreviation made up of the initial letters of English names of its components: "Software", "Hardware", "Environment", "Liveware" (Figure 1).

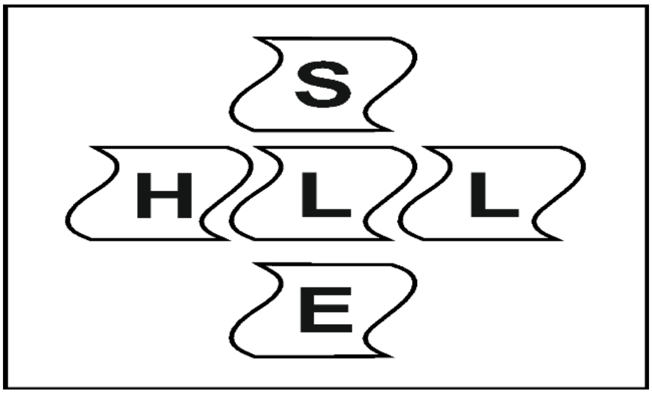

Figure 1. Diagram illustrating the conceptual SHEL model
(Safety Management Manual (SMM) Doc 9859 AN/474)

The key components of the model with a brief description are given below.

Subject (Liveware) - Object (Hardware) (L-H).

This interface is the most commonly considered and analyzed interaction of objects in all studies related to the human factor.

Subject (Liveware) - Software (L-S).

Interface between document systems supporting the workflow (instructions, maps, diagrams, and checklists) and software.

Subject (Liveware) - Subject (Liveware) (L-L).

Relationships between employees in a team shows both the relationship between a person and another person, and the relationship between a person and groups of people that exist within a team.

Subject (Liveware) - Environment (L-E).

This interaction shows the influence of external factors on humans, including weather, ecology, adverse effects of machines and mechanisms, and so on.

The SHEL model is arguably the most widely used in the world.

Summarizing the history of development of various approaches to the human factor, it can be noted that the first wave of interest in the human factor (Figure 2) in management science took place in the late 40s - early 60s of the XX century, when the “weight” of the human factor was about 30-50%. [21]

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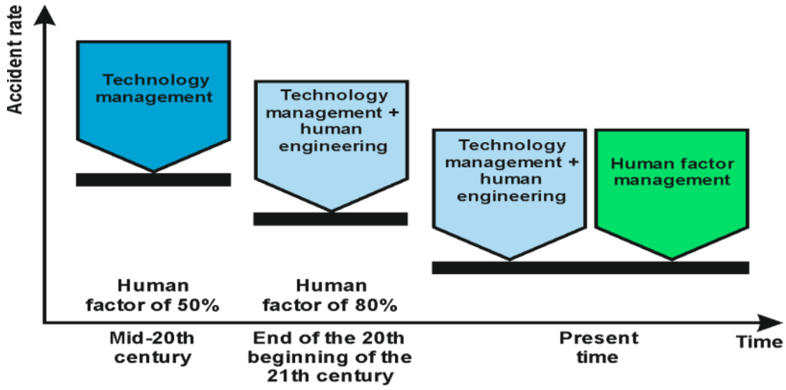

Figure 2. Change in the rate of the human factor in industrial accidents.

In the late XX - early XXI centuries, as a result of the scientific and technological revolution, new, safer technologies were created, taking into account the peculiarities of human interaction with production equipment. The number of accidents has dropped sharply, but the "weight" of the human factor has grown to 70-90% [17]. In this regard, it can be concluded that the human factor was underestimated.

Therefore, at present both the business community, the government and social structures look for new effective theories and technologies for managing the human factor in cases where a person cannot be replaced by a machine.

This work is devoted to this issue.

New Conceptual Model of Human Factor

The key ideas of the new conceptual model of the human factor have been elaborated and outlined by the author of this article. The diagram in Figure 3 below illustrates the key concepts of the author further reasoning.

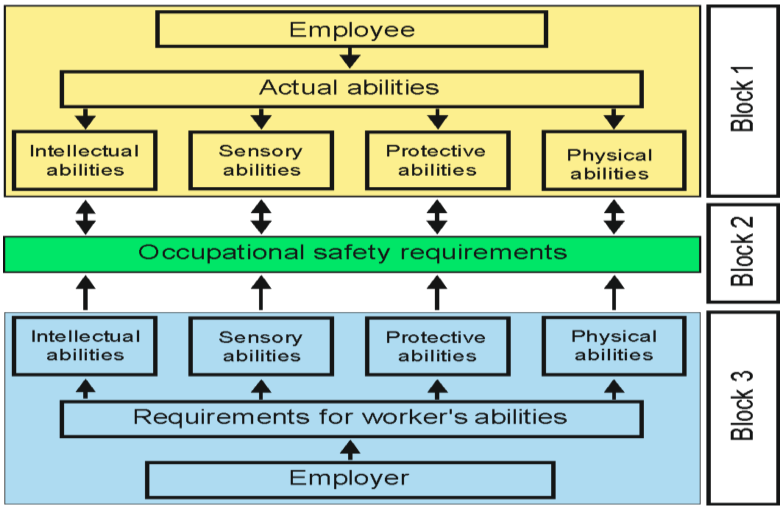

Figure 3. Diagram of the human factor conceptual model

Let's assume that any person has a certain set of abilities that allow him (or her) to live and work safely. In order not to complicate this model, we distinguish four fundamental elements in the set of abilities:

1. Intellectual abilities: the ability to apply knowledge, skills, experience and mental abilities in practice to perform work with minimal risk of harm to health.Sensory abilities: abilities that allow the control of the environmental hazards using the senses (sight, hearing, smell, touch, feeling of pain).

2. Protective abilities: the ability to tolerate certain loads of environmental factors (physical, chemical, biological impacts) and the labor process (workload and intensity) without harm to health.

3. Physical abilities: a set of human physical abilities (speed, strength, endurance, agility, flexibility) required to perform specific actions.

The author believes that the proposed elements of the set of abilities are sufficient to build the model, from the point of view of occupational safety, but he also understands that in some cases it is advisable to expand or limit this set. For example, detailed intellectual abilities, dividing them into mental abilities and psychic abilities. In some cases, it is reasonable to combine physical and protective abilities when considering the use or creation of personal protective equipment (PPE).

The author does not consider the systemic qualities of a person acquired during work and communication (moral principles, psychological and psychophysiological characteristics, and so on), believing that all of them are manifested through human abilities. A detailed consideration of the systemic human properties is necessary for developing methods that enable formation of the required unique and original qualities, but this is a matter of separate work.

At every moment, any person has a certain set of abilities, which we will call:

Actual Set of Abilities (ASA), that is, the demonstrated ability to safely perform a given job, based on the key aspects: intellectual, sensory, protective, and physical abilities (Figure 3. Block 1. Employee)

On the other hand, the employer has its own set of requirements for the employee's abilities, which are necessary for the successful performance of work in accordance with the employment contract:

Required Set of Abilities is a set of requirements for the intellectual, sensory, protective, and physical abilities of a person, which are necessary to perform a given job. (Figure 3. Block 3. Employer)

Usually, the requirements of an employer who defines the required set of abilities, and the requirements of workers with an actual set of abilities do not coincide. In Block 2, Reconciliation, the actual set and required set of abilities are reconciled, taking into account the labor protection requirements set forth in the conventions and recommendations of the International Labor Organization (ILO), and state and local regulations on labor protection.

The main idea of the proposed conceptual human factor model is to compare the Actual and Required Sets of Abilities, from which the following definition is derived:

Human Factor is the difference between the actual set of human abilities and the required set of abilities, which varies with time and space.

Based on this definition, the conceptual human factor model can be assigned the following name: DARA Model (Difference between Actual and Required Abilities).

This definition can be represented as a simple formula:

$$HF = ASA - RSA \quad (1)$$

where:

HF is the human factor;

RSA is the required set of abilities; and ASA is the actual set of abilities.

Before numerical calculations of the human factor, it is necessary to make a quantification, that is, to convert qualitative characteristics into quantitative values.

Thus, the evaluation of the human factor by formula (1) will produce the following results:

If RSA > ASA, then HF is negative. In this case, the human factor has a negative connotation, falls into the category of dangerous and harmful production factors, and the probability of accident exceeds the admissible accident rate.

If RSA = ASA, then HF is a neutral value, the human factor has a neutral connotation, and the probability of accident meets the admissible accident rate.

If RSA < ASA, then HF is a positive value, the human factor has a positive connotation; the employee's actions, in general, ensure high-quality and safe performance of work, and the probability of accident is lower than the admissible accident rate.

Consequently, within the proposed conceptual model, the human factor can have not only a negative meaning, according to human factor traditional visions, but also have a neutral connotation and acquire positive characteristics.

To demonstrate the capabilities of the conceptual model, let's consider a few examples:

an example of changes in the human factor over time; example of changes in the human factor in space; an example of assessing the reliability of the human factor and the accident risk; an example of an approach to managing the human factor.

Changes in Human Factor over Time

In this chapter, we consider an example that demonstrates changes in the intellectual aspect of the human factor over time through the learning process (Figure 4).

In this case, we assume that:

Initial Set of Actual Abilities (ISAA) is the level of the initial actual abilities of a person before starting to perform his job duties.

As a rule, the ISAA is below the requirements for the intellectual abilities of an employee. Upon hiring, the employee undergoes occupational safety training before starting to perform his duties. During training, the intellectual aspect of the ISAA increases and the human factor moves from the negative area to the positive area of the curve (ascending part of the curve in Figure 4).

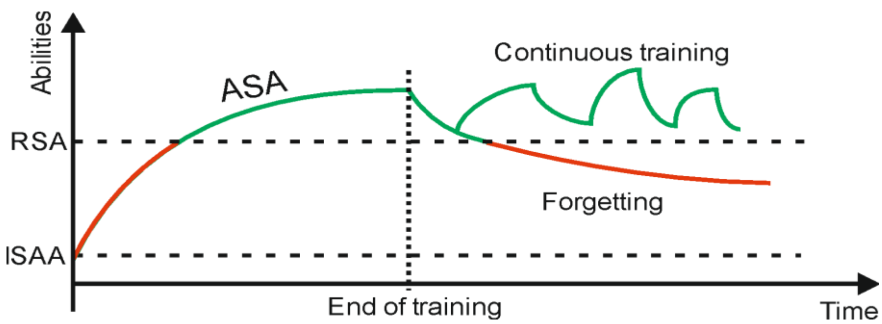

Figure 4. Changes in the intellectual aspect over time

After the end of training, the employee forgets the studied material with time, and the intellectual aspect begins to decline, which leads to a gradual return of the human factor to the area of negative values (descending curve in Figure 4).

To maintain the intellectual aspect of the human factor at the level necessary for the safe performance of work by employees, continuous learning technologies are used (fluctuating part of the curve in Figure 4).

Within the framework of the "Vision Zero and 7 Golden Rules" a program implemented by the International Association for Social Security (ISSA) [10], experts have developed and implemented a methodology for continuous professional training on occupational safety by individual programs using video information technologies. The methodology certainly improves the professional competence and personal responsibility of employees associated with occupational safety, and promotes safe behavior habits at work place.

The practice of using this methodology at a number of large enterprises has shown that the system of continuous training on occupational safety in the form of pre-shift express training for workers reduced the number of accidents at work by 1.5-3 times within 2 or 3 years. [20, 22]

Continuous training is applied not only to maintain existing occupational safety knowledge, but also timely provides employees with new knowledge, which will further reduce the number of industrial accidents.

Nowadays, continuous training has no alternatives, since the scientific and technological revolution has significantly reduced the term of relevance of knowledge acquired during training. In general, half of the knowledge that employees acquired during training in the thirties and forties of the last century was relevant for 30-40 years, the knowledge acquired in the sixties and seventies was relevant for about 10-15 years, and now the term of relevance has decreased to a few years.

UNESCO and WCLLL (World Committee for Lifelong Learning) are promoting the concept of lifelong learning around the world, and the author (member of the WCLLL) relied on that method when creating the methodology of continuous pre-shift express training of workers.

Changes in Human Factor in Space in Context of Working Conditions

One of the first conventions adopted by the International Labor Organization was the convention on working hours in industry, which can be considered the first international instrument related to occupational health. This document introduced restrictions on the workload and intensity of labor by establishing the 8-hour working day. From that moment on, the ILO in fact became an international coordinator for occupational safety, uniting the efforts of the countries in developing hygienic requirements that correspond to evolution of industries and the human society [18].

At the same time, each country, acting in line with the ILO's concepts, develops its own national hygienic rules and regulations, consistent with its economic structure, economic situation, working conditions, and so on.

Let me consider in more detail how working conditions are classified in Russia and, using this classification, show how the human factor changes in space.

According to the applicable Russian legislation, all workplaces undergo a special assessment of working conditions according to specific rules [5, 25]. Within the special assessment of working conditions, various harmful and hazardous factors of the working environment are measured, including physical, chemical and biological factors. In addition, such harmful and dan-

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gerous factors as workload and intensity of labor are also evaluated.

During the special assessment of working conditions, workplaces are assigned a class of working conditions based on the results of measurements of harmful and dangerous factors, which reflects the impact of harmful and dangerous workplace factors on human health. The higher the class is, the more difficult working conditions are at a workplace.

To illustrate this idea, let me consider this classification of working conditions. [25]

Optimal working conditions (class 1) are labor conditions in which there is no impact of harmful and (or) hazardous workplace factors on the employee, or the impact of which does not exceed the levels established by the working condition standards (hygienic standards); such conditions are approved as safe for humans and ensure stimulus for maintaining a high level of employee performance.

Admissible working conditions (class 2) are labor conditions under which the employee is exposed to harmful and (or) hazardous workplace factors, the impact of which does not exceed the levels established by the working condition standards, and the affected functional state of the employee's body is restored during regulated rest or by the beginning of the next working day (shift).

Harmful working conditions (class 3) are occupational conditions under which the exposure to harmful and (or) hazardous workplace factors exceeds the levels established by the working condition standards (hygienic standards), and include the following subclasses:

1) subclass 3.1 (harmful working conditions of the 1st degree) covers working conditions under which the employee is exposed to harmful and (or) hazardous workplace factors, after the impact of which the affected functional state of the employee's body is restored, as a rule, for a longer period of termination of hazardous factor effect, than the beginning of the next working day (shift), and the risk of health damage increases;

2) subclass 3.2 (harmful working conditions of the 2nd degree) covers working conditions under which the employee is exposed to harmful and (or) hazardous workplace factors, the impact of

which can cause persistent functional changes in the employee's body, leading to initial forms of progressive occupational diseases or occupational diseases of mild severity (without occupational disability) arising after prolonged exposure (fifteen or more years) to such factors;

3) subclass 3.3 (harmful working conditions of the 3rd degree) covers working conditions under which the employee is exposed to harmful and (or) hazardous workplace factors, the impact of which can cause persistent functional changes in the employee's body, leading to progressive occupational diseases of mild and moderate severity (with occupational disability) during the period of employment;

4) subclass 3.4 (harmful working conditions of the 4th degree) covers working conditions under which the employee is exposed to harmful and (or) hazardous workplace factors, the impact of which can lead to severe forms of occupational diseases (with permanent occupational disability) during the period of employment.

Hazardous working conditions (class 4) are occupational conditions under which the employee is exposed to harmful and (or) hazardous workplace factors, the impact of which during the whole working day (shift) or its part can threaten the health and life of the employee, and the consequences of exposure to these factors cause a high risk of developing an acute occupational disease during the period of employment.

The above classification of the intensity of human exposure to workplace factors can be illustrated using Shelford's law of tolerance [28]. The law of tolerance formalizes one of the fundamental principles of ecology. According to this principle, the presence or the well-being of a population of any organism in a given habitat depends on a set of environmental factors, and the organism has a certain range of environmental tolerance (endurance) to each of those factors. The range of tolerance for each factor is limited by its minimum and maximum values, within which the organism can exist.

The degree of well-being of a population, in particular human one, is usually represented as a bell-shaped curve of environmental tolerance with a maximum corresponding to the optimal value of a given factor for the human body or the maximum environmental tolerance, and descending parts corresponding to a gradual decrease in environmental tolerance or oppression of the human health by a given factor up to death threat.

As we can see from Figure 5, the optimal and admissible working conditions (classes 1 and 2 of working conditions) are in the area of maximum environmental tolerance in terms of temperature.

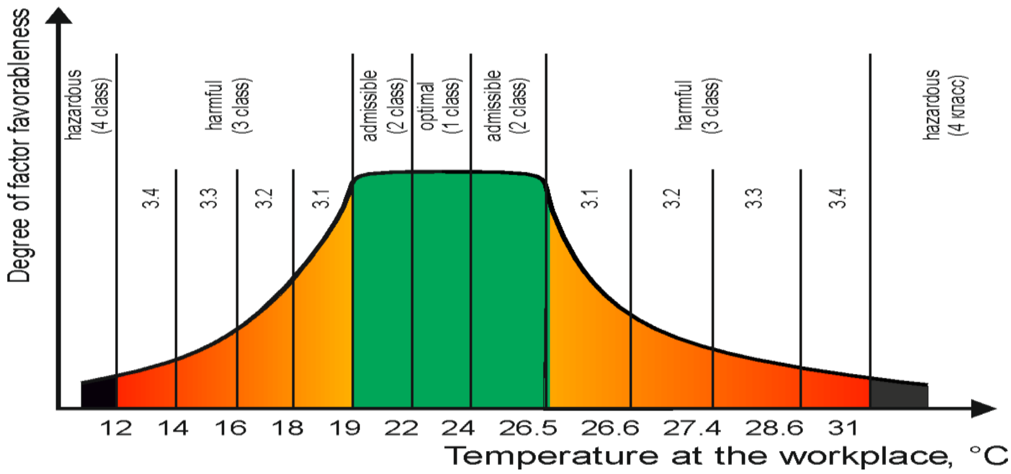

Figure 5. Graphical illustration of relationship between Shelford's law of tolerance and classes of working conditions by temperature factor.

Working conditions of the 3rd class, or harmful working conditions, are characterized by a constant deviation from the permissible levels of temperature load, the work provokes inhibition of vital activity - overheating or hypothermia of the human body, which, as established in practice, often leads to occupational diseases. Working in hazardous working conditions (class 4) can lead to death, even during one work shift.

By way of example of changing the human factor in space, let's examine one shift of a coal mine worker. To simplify the task, we exclude all harmful factors except for the coal dust.

Let me analyze the worker's path to his main workplace, where, according to previously

determined working conditions, the level of dustiness in the mine atmosphere reaches 40 mg/m^3, which corresponds to class 3.2 of working conditions [25]. The worker is provided with appropriate personal protective equipment that allows him to work under the working conditions class 3.2 in terms of the dust factor.

At the beginning of the shift, the worker is in the office and amenity rooms, where he receives work orders and prepares for performing work duties. In these premises, the working conditions correspond to the second class (RSA = 2 class of working conditions by the dust concentration factor or RSA = 10 mg/m^3).

HF=ASA-RSA, HF =40 mg/m^3 –10 mg/m^3 =30 mg/m^3

The human factor at this workplace is positive and is equal to 30 mg/m^3.

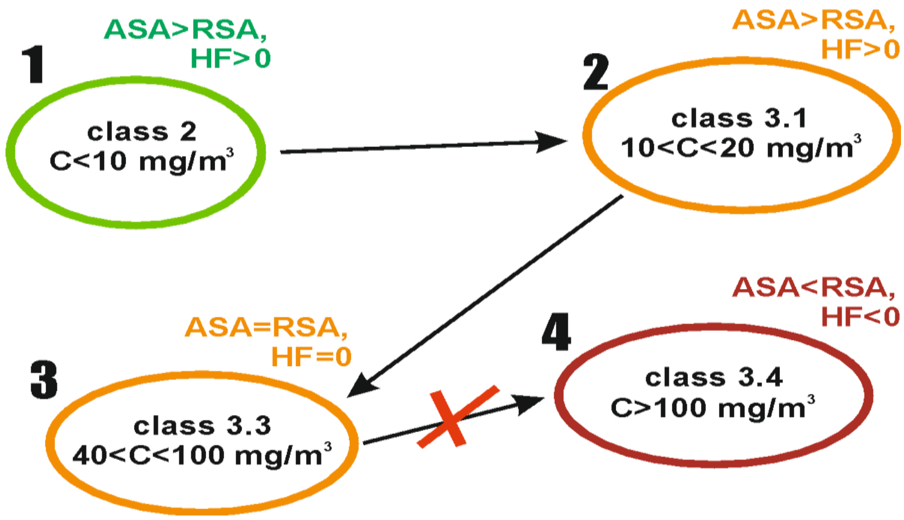

Figure 6. Changes in human factor in space

Then the worker moves to his main workplace in the mine, where the dust concentration can reach 20 mg/m^3, which corresponds to class 3.1 of working conditions, and RSA = 20 mg/m^3.

HF = ASA - RSA, HF = 40 mg/m^3 - 20 mg/m^3 = =20 mg/m^3

The human factor at this workplace is positive and is equal to 20 mg/m^3.

Having reached the main workplace, the worker begins to perform the assigned work. At the main workplace, the working conditions are of class 3.2, which corresponds to a concentration of airborne coal dust of up to 40 mg/m^3.

HF = ASA - RSA, HF = 40 mg/m^3 – 40 mg/m^3 = = 0 mg/m^3

Human factor at this workplace is zero, and the worker can successfully perform his job duties.

Near his workplace, a drifting machine is working, the dust content of the air corresponds to class 3.3 of working conditions, and the dust concentration reaches 100 mg/m^3.

HF = ASA - RSA, HF = 40 mg/m^3 - 100 mg/m^3 = = -60 mg/m^3

The human factor at this workplace is negative, and additional measures are required to protect the worker from dust.

This example demonstrates the relationship between the model and working conditions. In this case, the human factor is measured in units of dust concentration, mg/m³, which looks unusual. However, this is how health workers involved in occupational safety measure the human protective abilities for developing hygiene criteria, using kilograms, hours, and degrees, as shown in Table 1.

Table 1.

Units of human factor measurement for different elements of the set of abilities [5,25]

	Class of working conditions				
	Optimal	Admissible	Harmful		
	1	2	3.1	3.2	3.3
Intellectual abilities					
Indicators of the labor process intensity:	Task processing and execution	Task processing, execution and check	Task processing, check and	Control and preliminary work on the	
distribution of functions according to the degree of task complexity			control over execution	distribution of tasks to other persons	
Sensory abilities					
Monitoring screens of video terminals with alphanumeric type of information display, (hours per shift):	Up to 2	Up to 3	Up to 4	More than 4	
Protective abilities					
Coal dust concentration without free SiO2, mg/m3	-	<10	11-20	21-40	41-100
Physical abilities					
Total weight of goods moved during each hour of the shift from the working surface, for men, kg	up to 250	up to 870	up to 1,500	More than 1,500	

In some cases, a worker may be affected by several harmful factors at the same workplace simultaneously. In this case, the human factor is calculated for each factor separately.

Assessment of the Human Factor Reliability and Occupational Accident Risks

As another example of measuring the human factor according to the proposed model, I will show the relationship of the human factor with the main provisions of the reliability theory.

In 1926, M. Mayer [23], for the first time used statistical methods for assessing the strength of structures. At the first stages of aviation development characterized by the implementation of electronics and automation means, the reliability theory begins to evolve rapidly as a scientific discipline that creates and studies methods to ensure the efficiency of technical systems during their operation. Currently, this approach is an effective tool that has ensured the creation of reliable machines and equipment that have sharply decreased the number of accidents caused by equipment failures.

Reliability theory is the product of collective creativity created by the efforts of a large number of scientists. Through joint conferences and symposia, Soviet and American scientists developed the conceptual apparatus of the reliability theory and a system of quantitative indicators of various reliability properties. In particular, it was established that "Reliability is a property of a facility allowing it to preserve the preset values of all parameters in the course of time, which characterize the ability to perform the required functions under the preset conditions and conditions of use, maintenance, storage and transportation" [8].

It is difficult to say whose contribution is the most important, but it can be noted that the works of J. Neumann, K. Shannon, A. Pearce, F. Proshan, A. N. Kolmogorov, B. V. Gnedenko, and Yu. K. Belyaeva had significantly contributed to the creation and development of the reliability theory.

On the basis of these achievements, a set of methods was created that are aimed at assessing the reliability of the human factor within the human-machine system. Methods for assessing the reliability of the human factor are summarized in the standard [15]. According to this standard, "human reliability is the ability of a person to perform a task under specified conditions within a specified period of time, subject to given constraints."

Using this definition as a basis, in the context of this work I give the following definitions of the reliability of the human factor and related parameters:

Reliability of the Human Factor is the ability of a person to provide a non-negative value of the human factor during a given period of time.

Failure means termination of the performance of job duties necessary to achieve the goal due to an accident.

Probability of Failure-Free Performance means the probability that an employee will not experience an accident within a given period of time.

Accident Rate is the ratio of the number of accidents to the average number of employees.By applying the approaches of the reliability theory to the human factor, I formulate RSA and ASA as follows:

RSA$_a$ is the required probability of work without accidents of varying severity during a given period of time;

ASA$_a$ is the actual probability of work without accidents of varying severity during a given period of time.

Let's consider two basic concepts of the theory of human factor reliability, which are related to each other, but are opposite in meaning: the probability of an accident ***P*** and the probability of work without accidents ***Q***:

$$P = \frac{N_m}{N_0} \quad (2)$$

$$Q = 1 - P = 1 - \frac{N_A}{N_0} = \frac{N_0 - N_A}{N_0} \quad (3)$$

where:

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P is the probability of an accident;

Q is the probability of work without accidents; N_A is the number of accidents; N_0 is the total number of workers.

Since statistics related to accidents are usually published annually, unless otherwise explicitly stated, further in the text we will assume that the probabilities of accidents are considered in a time interval of 1 year.

Table 2 shows the initial data and the calculated probabilities of a fatal accident and an accident with absence from work for more than three days for 2003 according to the International Labor Organization [19].

Table 2.

Probability of industrial accidents for a number of countries of the European Union (EU-38)

Country	Total number of workers	Fatalities reported to the ILO (2003)	Accidents (absence from work for more than 3 days), reported to the ILO (2003)	Probability of fatal accident	Probability of accident (absence from work for more than 3 days)
1	2	3	4	5	6
Parameter / formula	N_0	N_F	N_A	$P_F=N_F/N_0$	$P_A=N_A/N_0$
Great Britain	27,820,800	174	164,767	0.0000062543	0.005922
Norway	2,269,000	49	23,767	0.0000215954	0.010474
Spain	17,295,900	722	872,610	0.0000417440	0.050451
Italy	22,133,000	916	545,446	0.0000413862	0.024644
For EU-38	145,426,442	4,465	2,805,547	0.0000307028	0.019291

Having the accident rate caused by human factor of 0.8 (see Introduction) and by using the Q

(3) formula, we obtain the probability of work without human accidents, which is displayed in columns 2 and 3 of Table 3:

$$ASA_{wf}= Q_{HFF}= 1 – 0.8·P_F \quad (4)$$

$$ASA_{wf}= Q_{HFA}= 1 – 0.8·P_A \quad (5)$$

Next, we will calculate the human factor according to the formula arising from formula (1),

$$HF_{wf} = ASA_{wf} – RSA_{wf}, \quad (6)$$

$$HR_{wa} = ASA_{wa} – RSA_{wa}, \quad (7)$$

where:

RSA_{wf} is the required probability of work without fatal accidents during a given period of time;

RSA_{wa} is the required probability of work without accidents with absence from work for more than three days, during a given period of time;

ASA_{wf} is the actual probability of work without fatal accidents during a given period of time;ASA_{wa} is the actual probability of work without accidents with absence from work for more than three days, during a given period of time.

Based on the above formulas, Table 3 shows the results of calculations of the human factor reliability in terms of fatal accidents and absence from work for more than 3 days for some EU countries. As the

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required level of reliability of the human factor for fatal accidents and accidents with absence from work for more than 3 days, the corresponding levels were selected for the EU-38 group of countries. [19]

Table 3.

Calculation of the human factor for some countries of the European Union from EU-38

Country	Probability of work without fatal accident caused by human factor, Q_{HFF}	Probability of work without accident caused by human factor, with absence from work for more than three days, Q_{HFA}	Human factor by fatal accidents, HF_F	Human factor by fatal accidents with absence from work for more than three days, HF_A
1	2	3	4	5
Parameter / formula	$Q_{HFF}=1-0.8{\cdot}P_F$	$Q_{HFA}=1-0.8{\cdot}P_A$	$HF_F=Q_{HFF(country)} - Q_{HFF(EU\text{-}38)}$	$HF_A=Q_{HFA(country)} - Q_{HFA(EU\text{-}38)}$
Great Britain	0.999994997	0.995262049	0.0000195588	0.0036417753
Norway	0.999982724	0.991620273	0.0000072859	0.0070537637
Average for EU-38	0.999975438	0.98456651	-	-
Spain	0.024644016	0.999966891	-0.00000883	-0.0249279825
Italy	0.999966891	0.980284787	-0.00000855	-0.0042817222

In the given example, we can see that during the specified period of time (one year), the human factor is positive for Great Britain and Norway, but it is negative for Spain and Italy both in terms of fatal accidents and accidents with absence from work for more than 3 days.

By expanding approaches of the reliability theory in respect to the human factor, we can assess

how the reliability of the human factor changes with the employee's experience.

Based on formulas (2) and (3), it is possible to determine the following model dependencies typical for the extractive industry (coal mines, logging, gas and oil production) and the construction industry. In my calculations, I used indicators related to accidents with absence from work for more than three days.

Probability of an accident at the workplace correlates with the work experience and age of the worker, which generally can be depicted as a curve (Fig. 7), and it is assumed that in the initial period of work the worker is exposed to the increased risk of accidents (Fig. 7, segment I); the reliability theory defines this segment as the running-in period. With about five years of experience, the probability of an accident with the worker decreases, as the worker gradually gains insight into the production process and associated hazards. In addition, with increasing work experience and age, the worker becomes more careful and prudent, acquires the skills to perform work safely, which leads to a decrease in the probability of accidents that becomes constant for about 15 years (Fig. 7, segment II). In reliability theory, this period is called the period of normal operation, when the probability of failures is almost constant.

Figure 7. Density of probability of accidents in function of the work experience However,

with further increase of age, the worker's physical and intellectual abilities begin to

decline, and the probability of accidents rises. The figure shows this trend as the rise of the curve of probability of accidents (Fig. 7, segment III). In the reliability theory, this segment is called the aging period.

In some cases, it is more convenient to consider the opposite of the probability of accidents - the probability of work without accidents. Then the curve shown in Figure 7 using formula (3) transforms into the curve shown in Figure 8.

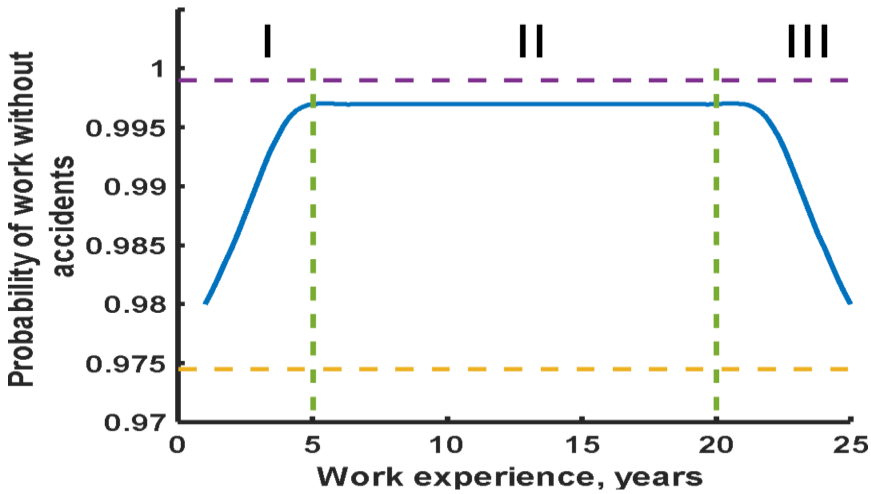

Figure 8. Density of probability of work without accidents in function of the work experience

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The approach, where the reliability criterion is the probability of work without accidents instead of the probability of accidents, makes mathematical operations with numerical values of the reliability

parameters more clear.

This figure also shows two levels of RSA. RSA_1 is the required set of abilities, which is lower than the actual set of abilities throughout the entire work experience. RSA_2 is the required set of abilities, which is higher than the actual set of abilities throughout the entire work experience. Thus, the human factor throughout the work experience is always positive if the established requirements correspond to RSA_1, and negative if the established requirements correspond to the RSA_2 level.

Let consider how the probability of work without accidents changes over 25 years, taking into account the work experience of a worker (Figure 9). The figure has three segments. Segment I corresponds to the initial period where the probability of work without accidents decreases sharply due to the low competence of the worker. As the worker learns, the rate of decline in the probability of work without accidents slows down as the person acquires the necessary skills and experience to work safely. Segment II corresponds to the decreasing probability of work without accidents for an experienced worker over time. In segment III, the rate of decrease in the probability of work without accidents rises again due to declining elements of the set of abilities caused by the natural aging of the body.

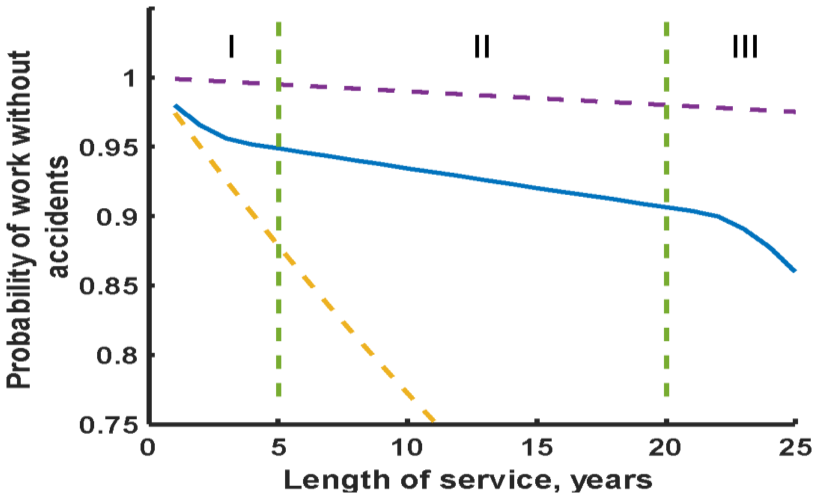

Figure 9. Probability of work without accidents over time in function of the worker's experience

According to Figure 9, 98 of 100 workers hired simultaneously will work without accidents during the first year, and 88 of 100 workers will have no accident during 25 years.

Let demonstrate one of the methods for assessing the accident risk with absence from work for more than 3 days.

For this purpose, the author believes that the definition of accident risk given in the standard [9] is the most relevant.

Risk is a combination (product) of the probability (or frequency) of harm and the severity of this harm.

The severity of damage (harm to health) is defined as the number of days of absence from work. Then, the risk is the probability of an accident, after which the victim will be absent from work for more than 3 days (time spent on health recovery). Let build the correlation of the accident risk (with absence from work for more than 3 days) with the work experience of a worker (Figure 10). According to the figure, the risk of an accident increases over time. The risk increases faster in the area of ability formation (segment I) than in segment II, where the actual set of abilities remains fairly stable. In segment III, the accident risk rises due to decline in all the elements of the set of abilities caused by natural aging of the body. Over the 25-year work experience shown in the figure, the accident risk rises from 0.02 to 0.12.

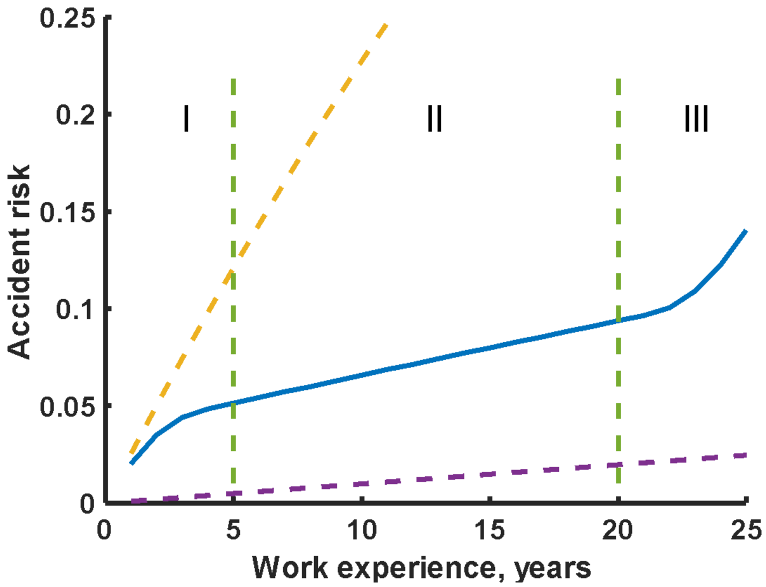

Figure 10. Accident risk over time in function of the worker's experience

This means that 2 of 100 workers, who entered work at the same time, will have accidents with absence from work for more than 3 days during the first year, and 12 workers will face an accident the same harm to their health during 25 years.

I hope that in this example, I was able to show the suitability of the proposed conceptual model for calculating the human factor and assessing the accident risks using the reliability theory.

The proposed approach to measuring the human factor, taking into account the provisions of the reliability theory, allows using most of the existing methods for analyzing the reliability of the human factor (HRA): Accident Sequence Evaluation Program (ASEP), FMEA/FMECA (Failure Mode and Effect Analysis/ Failure Modes, Effects, and Criticality Analysis), Technique for Human Error-Rate Prediction (THERP) and so on.

Human Factors Management Approaches

Initially, work execution techniques and the corresponding occupational safety measures were only created within the families of artisans or in closed professional communities. As a result, that measures were of scattered and non-systematized nature, were kept secret and not widely used. Labor protection mostly practiced an empirical approach based on perso-

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nal experience and local manifestations of unfavorable factors directly related to production technology.

A modern enterprise has many prerequisites for improving working conditions. The economic side of all introduced innovations is usually taken into account first. Entrepreneurs and workers, in general, have the same interest in eliminating occupational risks and improving working conditions.

Let consider a few examples of solving the tasks of improving working conditions. In 2018-2019, research institutes of a number of member states of the European Community (Denmark, Netherlands, Belgium, etc.) performed a series of research projects, subsidized by the EU, to identify the reasons for the low impact of legislation on the development and implementation of OSH programs at enterprises [3]. The task was to identify the reasons why the management of some organizations is not interested in developing and disseminating these programs, and the impetus of the leaders of other companies who have already developed and implemented health and safety programs in their organizations. As a rule, the refusal to implement programs for improving working conditions and occupational safety was detected at small and medium-sized enterprises with low economic efficiency and labor discipline. On the other hand, the results of the studies showed that the reasons for the implementation of health and safety programs in the workplace were as follows:

- general positive attitude of both the employer and employees to the improvement of working conditions, health and safety;
- availability of an occupational safety management system at the enterprise;
- management striving to create a stable image of the enterprise as safe and applying the improved working conditions;
- need to reduce the number of production risks (especially at enterprises with a high rate of human-driven production risks);
- reduction in the disease rate, loss of working time and sick leave costs;
- availability of programs developed by external experts and invited consultants;
- compliance with the instructions of the labor inspectorate.

The European researchers [3] concluded that occupational health and safety programs are prevalent where enterprise management understands the economic and organizational impact of improving occupational health and safety in modern production management. At the same time, they came to the conclusion that the assessment of industrial risk and attention to the HF encouraged a number of advantages of economic, social and humanitarian nature. At the enterprise level, the assessment of the HF and the elimination of occupational risk improve the following indicators of the labor process:

-preventing occupational diseases and accidents, which leads to significant decrease in the amount of compensations for these factors;

- reducing the number of sick leaves and staff rotation;
- improving mutual understanding between the employer and workers;
- increasing the importance of measures taken to improve working conditions;
- encouraging worker's initiatives and improving production relations;
- improving the quality of labor and products;
- increasing productivity and efficiency of labor;
- improving the overall production culture;

- favorable conditions for production insurance, bonuses for insurance of the personnel of the enterprise;
- improving the enterprise image as safe, efficient and civilized in the labor market;
- creating more profitable (in terms of safety and culture) jobs.

As the economic efficiency of the enterprise grows, workers formulate higher requirements for improving working conditions, assessing occupational risks and promoting general workplace safety. For certain specialized professions, working conditions can be a decisive factor in attracting skilled workers. Employers are aware of this and, in turn, address legislators, demanding the development of new rules and regulations for assessing working conditions and industrial risks.

The EU Council Directive 89/391/EEC [1] has enlightened the improvement of the occupational safety management system, and obliged employers to assess occupational risk on the legislative level in the EU member states. Directive [1] requires the employer to take the necessary measures to ensure the health and safety of workers based on the following principles of labor safety:

Article 6. 2(e) adapting the work to the individual, especially as regards the design of work places, the choice of work equipment and the choice of working and production methods, with a view, in particular, to alleviating monotonous work and work at a predetermined work-rate and to reducing their effect on health.

Article 6. 3(a) - evaluate the risks to the safety and health of workers, inter alia in the choice of work equipment, the chemical substances or preparations used, and the fitting-out of work places.

At the same time, Directive 89/391/ EEC introduced two new concepts: assessment of working conditions (AWC) and HF-based occupational risk assessment (ORA). The OSH experts identified the

following differences between AWC and ORA.

For example, AWC covers all labor aspects in the workplace and is mainly aimed at improving the work environment. AWC takes in account all factors of labor activity, such as the physical and chemical elements of the working environment, ergonomics, labor protection, mental and physical stress, and the general organization of labor activity at the enterprise, and does not always require a quantitative analysis of the economic side of production. Consequently, AWC implies a broader survey aimed at identifying potential hazards and improving the work environment. The ORA has a narrower sense. It is focused on identifying and assessing occupational risk, determining the HF impact on the working environment. ORA's main goal is to determine and quantify the production risks associated with HF, applied technology and equipment, and to develop and implement safe labor solutions in production. EU experts emphasize that the implementation of both the AWC and the ORA requires certain basic knowledge and practical skills and therefore both activities must be carried out by qualified specialists.

Research outcomes show that modern practice of both AWC and ORA gives the best results in those enterprises where there is close interaction between employers and workers, aimed at solving the HF problems, identifying and assessing production risks, and improving working conditions and safety.

The current vision of labor protection as a system of preserving the life and health of workers in the process of work, consisting of a set of legal, socio-economic, organizational, technical, sanitary, hygienic, medical and

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preventive, rehabilitation and other activities, allows designing various efficient OSH management systems as per specific needs, selecting only the required elements from the general set. Consequently, all currently designed OSH management systems are to some extent involved in the management of the human factor.

Developed OSH management systems can be conditionally divided into four hierarchical levels:

1. International occupational safety management system.

Development and timely adjustment by the international community of the fundamental

principles of OSH management. Under the guidance and direct participation of the ILO, 190 Conventions and 2006 Recommendations have been developed [24].

2. *National occupational safety management system.*

Management of the system for preserving the life and health of workers in the process of work, performed by an individual state. As a rule, the state:

- establishes criteria for working conditions and monitors compliance with them, and so on;
- establishes the procedure for organizing and conducting training on labor protection of employees and monitors its observance.

3. Occupational safety management system at the enterprise (employer's responsibility) level.

The occupational safety management system is considered as a component of the general management system of an organization, which must ensure occupational safety of personnel at the workplace. Occupational safety management system at the enterprise level:

- develops, implements and maintains established procedures to guarantee the identification of hazards, assessment, regulation and control of accident risks and occupational diseases;
- identifies the needs and provides training for workers on occupational safety;
- ensures working conditions under which the impact of harmful and hazardous production factors on workers is excluded or reduced to safe limits.

4. Personal occupational safety management system.

The personal occupational safety management system is based on the knowledge of labor protection rules, skills and abilities of safe work practices, and experience allowing to predict the development of dangerous events. The personal occupational safety system at work implies the collection of information about the hazards that arise during work by using the senses or appropriate

controls, assessment of hazards and appropriate measures taken to eliminate them.

International occupational safety management system should be consistent with the general principles of international law and cooperation; national occupational safety management systems should be consistent with state governance systems, national laws, and social and political principles; the employer's occupational safety management system should comply with the overall business management systems; the personal occupational safety management system should be consistent with the social environment, mentality, employer requirements, and other factors.

In the proposed model, the management of the human factor is based on various methods and techniques to achieve a non-negative value of the human factor. To make informed management decisions, as a rule, it is necessary to analyze the human factor in terms of all elements of the set of human abilities, including intellectual, sensory, protective and physical elements. At the same time, it can be noted that in some cases it is enough to select a reduced set of abilities for analysis, for example, intellectual and sensory elements.

Table 4 is a template according to which additional measures can be introduced into the existing occupational safety management systems at various levels to ensure effective management of the human factor. As an example of the implemented approach at the enterprise level, we analyze a set of management actions that must be taken into account when creating a corporate occupational safety management system.

Let me examine this table in detail.

The first column shows the levels of abilities with reference to working conditions (ISAA, SSA_1, SSA_2).

The first supplementary level of abilities (SSA_1) corresponds to the necessary improvement of the worker's abilities, which provides a positive value of the human factor under admissible working conditions due to the development of intellectual, sensory, protective and physical elements of human abilities.

The second supplementary level of abilities (SSA_2) corresponds to the necessary improvement

of the worker's abilities, which provides a positive value of the human factor in harmful working conditions with the use of technical means for upgrading the intellectual, sensory and physical elements of human abilities.

Each cell in the table summarizes the management actions required to ensure a positive human factor. Columns 3-6 of the table correspond to the elements of the set of abilities (intellectual, sensory, physical, protective abilities), which can be influenced to control the human factor. Lines 1-3 indicate the necessary actions in relation to the levels of abilities and working conditions (ISAA, SSA_1, SSA_2).

Table 4 .

Template of human factor management actions.

	Ability levels. Working conditions	Intellectual abilities	Sensory abilities	Protective abilities	Physical abilities
1	2	3	4	5	6
1.	Initial level of actual abilities (ISAA)	Testing intellectual abilities for compliance with working conditions and job duties	Testing sensory abilities for compliance with working conditions and job duties	Testing protective abilities for compliance with working conditions and job duties	Testing physical abilities for compliance with working conditions and job duties
2	First supplementary level of abilities (SSA_1) (admissible working conditions)	Ensuring the evolution of knowledge, skills and experience necessary for the safe performance of work	Training of the worker's sensory system for signs of danger perceived by the sense organs	Ensuring safe development of natural protective abilities (adaptation)	Improving abilities through the acquisition of physical skills for the safe performance of work.

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3	Second supplementary level of abilities (SSA_2) (harmful working conditions)	Providing workers with special electronic devices for access to information systems	Providing workers with technical means for monitoring working conditions	Providing workers with PPE in accordance with working conditions; treatment, preventive and rehabilitation measures, if necessary.	Providing workers with the necessary tools and devices.

Let me provide an example of working with this table.

The green cell of the table describes the main management actions to create the required level of protective abilities, ensuring a positive value of the human factor in harmful working conditions:

- providing workers with the required personal protective equipment for the respiratory organs, legs, arms, head, eyes, and so on;

- timely medical, preventive (medical examinations, medical and preventive nutrition, etc.) and rehabilitation measures (rehabilitation therapy, spa treatment, and so on).

For a more detailed analysis of the necessary management decisions on the human factor, each column of the matrix can be further divided into individual elements.

Intellectual abilities can be divided into knowledge, skills and experience. To ensure knowledge upgrade, various types of training are necessary, including lifelong learning approaches. To develop skills, practical training on the safe performance of work, including using virtual reality tools, is required. Experience, as everyone knows, is formed with the length of service, the accumulation of experience can be accelerated by analyzing various dangerous situations, accidents and incidents together with workers.

A similar division can be made with sensory abilities (vision, hearing, smell, touch, sensation of pain), protective (physical, chemical, biological factors, etc.) and physical abilities (speed, strength, endurance, agility, flexibility).

The implementation of these management actions given in the table shall provide a non-negative value of the human factor.

There are a large number of different OSH management systems aimed at preserving the life and health of workers, and the proposed template can serve as a useful additional tool to these systems in terms of human factor management.

Conclusion

This work proposes a new conceptual model of the human factor that defines the human factor as the difference in time and space between the actual level of human abilities and the required level of abilities.

Thus, if the required abilities are greater than the actual ones, then the HF has a negative value, and “human” can be assessed as a dangerous, harmful production factor, which corresponds to the traditional negative vision of the human factor.

If the actual abilities are higher than the required level of abilities, then the HF has a positive value, and the concept of "human factor" acquires positive connotation, and means that the worker's actions, in general, can ensure high-quality and safe performance of work.

The proposed model provides for using most of the existing methods for analyzing the reliability of the human factor (HRA) with respect to the production system operation.

The work provides several examples demonstrating capabilities of the proposed model in describing the development of intellectual abilities, considering working conditions, assessing the accident risks and complementing the existing occupational safety management systems with due account for the human factor.

The author believes that one of the most effective ways to ensure positive values of the HF is the continuous training of workers on occupational safety issues, which, as evidenced by practice, will reduce the number of industrial accidents by 1.5-3 times within 2-3 years.

The model allows using different units of measurement for the human factor, which represents a non-standard approach. However, this is how health workers involved in occupational safety develop hygiene criteria and measure the human protective abilities in kilograms, hours, degrees. Intellectual, sensory and physical abilities can be measured both in classes of working conditions and in specific factors characterizing working conditions.

The author demonstrated that the model enables us to assess the reliability of the human factor using standard procedures of the reliability theory.

The proposed model of the human factor corresponds to the current occupational safety

management systems and can lay a solid foundation for creating new occupational safety management technologies that will take into account the human factor.

Moreover, the author gives a template of impacts at the employer level, according to which additional measures can be introduced into the existing occupational safety and health management systems of various levels to ensure effective management of the human factor.

In the author's opinion, this approach can be applied to workers with disabilities. As a result of developing appropriate additional abilities of a worker, and due to creation of special working conditions and the use of dedicated tools, machines and protective equipment, the deficient individual elements of the initial human abilities will cease to be an obstacle to full-fledged labor activity, and the human factor will become positive.

Approaches proposed by this model can be applied in practice, namely, by introducing technologies of continuous express training of workers on occupational safety at enterprises level, which help assess the industrial accident risks caused by the incompetent actions of workers.

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ანოტაცია. წარმოადგენილია ადამიანის ფაქტორის ახალი კონცეპტუალური მოდელი (DARA მოდელი – Actual და Required უნარების სხვაობა), რომლის ფარგლებშიც ადამიანის ფაქტორი განისაზღვრება, როგორც ადამიანის რეალური შესაძლებლობებისა და სამუშაოს შინაარსით განსაზღვრული მოთხოვნადი შესაძლებლობების სხვაობა. მოყვანილია მაგალითები ადამიანის ფაქტორის ცვლილებების შესახებ დროისა და სივრცის ჭრილში. შეფასებულია ადამიანის ფაქტორის სანდოობა და უბედური შემთხვევების რისკები, გათვალისწინებულია თანამშრომლის პროფესიული სტაჟი. ასევე წარმოდგენილია ზემოქმედების შაბლონი დამსაქმებლის დონეზე, რომლის მიხედვითაც შესაძლებელია დამატებითი ღონისძიებების ინტეგრირება შრომის უსაფრთხოებისა და ჯანმრთელობის დაცვის არსებულ მენეჯმენტსისტემებში, სხვადასხვა დონეზე, ადამიანის ფაქტორის ეფექტიანი მართვის უზრუნველსაყოფად.

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