

Building a Morphological Model for Determining Hazards in the Working and Surrounding Environment

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Abstract- The paper presents a new morphological model for determining occupational and environmental hazards. The modern terminology and the complex of concepts intended for determining a hazardous and safe environment are examined. A classification of hazards is proposed depending on their origin and a morphological model is built. The latter can be used to determine hazards in the working and surrounding environment. Its significance is expressed in the possibility of transforming the ongoing phenomena into the effect of a defined hazard. Occupational and environmental factors in industrial enterprises are systematically presented in the following figures. Each production system operates in the conditions of a specific occupational and surrounding environment and can be represented by a generalised cybernetic scheme. In it, the control object is characterised by a large number of input control disturbing factors and output parameters. Their interaction is characterized by functional and non-functional inputs and outputs, respectively. When defining the hazard, the interaction of production systems with the working and surrounding environment or with other systems is taken as a basis. Presented are System S₁ for a production system at an industrial enterprise and S₂ for a system of its environment, which can be natural, artificial, urban, other production (human-machine) systems, etc. The environment S₂ is safe when the output impact factors (functional and non-functional parameters) created by the production system S₁ do not create hazards. The presented morphological model in industrial enterprises reflects a situation represented by the chain ‘phenomenon → action → effect’ described in a tuple. The process of building a morphological model for determining hazards in the occupational and surrounding environment of industrial enterprises goes through the following three stages. The universality of indicated morphological model application is dictated by the consideration of actually existing environmental factors and

the transformation of the hazardous phenomenon into a hazardous effect.

Keywords – effect, environment, hazard, model, morphological, system.

I. INTRODUCTION

Our society is subject to the impact of numerous and diverse hazardous phenomena, situations and events.

Depending on the causes of occurrence, hazardous events can be classified as anthropogenic, natural and combined.

- **Anthropogenic hazardous events** are divided into production, social, political, mixed, etc.

- *Production hazardous events* are related to the labour activity of people aimed at obtaining socially useful products. They can occur at all stages of the life cycle of production. They are associated with the extraction of natural resources; production of materials, energy and goods; storage, distribution, transportation; consumption, maintenance, reuse; recycling; waste, destruction.

Incidents, accidents, breakdowns, and catastrophes are production and technological hazardous events characteristic for all stages of the life cycle of production.

- *Politically hazardous events* are military conflicts which lead to human casualties, destruction of settlements, large economic losses, refugee flows and a number of other critical consequences of a humanitarian nature. The reasons for them can be social, ethnic tension, religious conflicts, border incidents, satisfaction of domestic and foreign political interests.

- **Natural hazardous events** are disasters, and they are classified into three main groups:

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- *geotectonic disasters* – earthquakes, landslides, volcanic activity;
- *meteorological and climatic disasters* – storms, hurricanes, cyclones, tornadoes, floods, extreme warming or cooling, prolonged droughts, rainfall, snowstorms, icing, hail;
- *other disasters* – desertified territories, forest and steppe fires, invasion of insects and plant pests.

• **Combined hazardous phenomena** are observed when a natural disaster interacts with a hazardous technical accident on a given territory.

In the Bulgarian language, the main interpretation of the word ‘hazard’ is the possibility of trouble, misfortune. This concept is used and applied in theories and models of industrial hazardous phenomena in order to describe them sufficiently fully and at the same time understand them in principle.

Each of the hazards has a source that increases and transmits them to the working and surrounding environment. The sources of the hazard can be of a subjective and/or objective nature, as well as the combination between them. Individuals, groups and organisations could generate individual and interconnected events, phenomena and processes in the natural environment and society.

Hazards arise from and can be associated with natural phenomena (such as earthquakes, floods, hurricanes, etc.) happening beyond the control of people and from situations (such as industrial accidents, ecological and social catastrophes, environmental pollution) in which man is the main risk factor. Risk factors in the working and surrounding environment are defined as a situation, event, impact or process that can lead to the occurrence of a certain hazard [1, 2].

A number of definitions of the term ‘hazard’ are known, formulated over time by various researchers. For example:

- ‘material, energy source or function that have the potential to cause illness, injury or death to personnel and damage to technical means and the environment’;
- ‘action or condition that causes harm and damage’;
- ‘physically defined situation with the potential for injury to people, destruction of physical and surrounding environment, as well as a combination of them’;
- ‘inherent potential that causes injury or damage to human health’;
- ‘something or some condition that acts or has the potential to cause trauma, damage or illness to health’;
- ‘probability of damage caused by a natural phenomenon, technical, organisational or human errors’;
- ‘potential for damage having the properties of a material or cause’;
- ‘activity, location, circumstance, event, phenomenon, process, situation or substance (regardless of where it occurred or was caused – within the boundaries of the workplace or outside it) that is an actual or potential cause or source of harm’ [3].

A hazard is the source that can cause injury or damage to health.

A situation can be defined as hazardous when risk circumstances exist and they can become a reason and conditions for violation of generally significant interests as well as when society is harmed.

A **hazardous situation** is any situation in which a person is exposed to one or more hazards. The zone of influence in and around the source where a person is exposed to the risk of injury or damage to health is defined as a **hazard zone** [4, 5].

The term ‘hazard’ is appropriate to be used in combination with other words that define its origin or the nature of the expected injury and damage to health such as: electric shock hazard, crushing hazard, cutting hazard, poisoning hazard, etc.

II. MATERIALS AND METHODS

Mechanical hazards – they are created by machine parts (or machined parts) and can be quantitatively and qualitatively defined in the production risk.

Electrical hazards – they are divided into two main groups in the working environment. In the first one, we have people touching live parts, i.e. parts that are normally under voltage (direct contact). The second group is more extensive and diverse in impact, but it is defined as people touching parts that have become live due to a malfunction, in particular due to insulation damage (indirect contact). The second group of hazards includes people approaching live parts, especially those with high voltage, inadequate insulation for the intended conditions of use or when people (or objects dropped by people) fall as a result of surprise caused by an electric shock. This group also includes electrostatic phenomena, such as people touching electrically charged parts or when creating conditions for static electricity.

Thermal hazards – this group includes direct impacts related to burns and scalds when in contact with objects or materials with extreme surface temperature, flames or explosions and radiation from heat sources. In summary, we can indicate that this group includes impacts harmful to health caused by a hot or cold working environment.

Hazards caused by noise (sound) impact – in the working and surrounding environment, sound waves are the main factor and source of impact. In the working environment, the hazards for personnel are associated with permanent loss of hearing acuity (with sound wave intensity above 130 Db), tinnitus, fatigue, stress, etc. With prolonged exposure to sound waves below the upper hearing threshold of 130 Db, other consequences may be loss of balance, weakening of attention, disturbances in the perception of spoken speech, sound signals, etc.

Hazards caused by vibrations – this group of hazards is associated with the propagation of mechanical waves in a rigid (inelastic) environment, and local vibrations (for example, when using hand tools) can lead to damage to the

peripheral nervous system and blood vessels. In occupational medicine, diseases resulting from vibration exposure are defined as neuralgic, bone and joint disorders, lumbalgia, sciatic nerve neuropathy, etc. Production premises can be a source of general vibrations that affect the entire body.

Hazards caused by radiation – the first group of radiations are related to the impact of electromagnetic waves from the electromagnetic spectrum. They can be low-frequency, radio-frequency and microwave radiations, as well as infrared, from the visible and ultraviolet part of the spectrum. X-ray and gamma radiations are part of the electromagnetic spectrum, with wide application in medicine and scientific research activities. The second group of radiations are a consequence of the spread and use of radioactive chemical elements in the working and surrounding environment. Their impact is expressed in the spread of α - and β -particles, as well as a flow of electron or ion, neutron radiations. The third group of radiations covers the application of laser technologies in the working environment [6].

Hazards created by materials and substances – depending on their origin and distribution in the environment, these can be chemical hazards – caused by contact with liquids, gases, vapours, fumes and dust having a harmful, toxic, corrosive and/or irritating effect, energy hazards from fire and explosion, or biological (for example, mold) and microbiological (viral or bacterial sources of infection) hazards [7].

Hazards created by failure to comply with ergonomic principles when designing a machine – first of all, the use of devices and appliances beyond their intended purpose leads to human errors and specific behaviour causing physiological consequences, resulting for example of unfavourable working postures, great or repetitive muscle efforts. The fundamental rejection of ergonomic requirements when designing production equipment can cause psychophysiological consequences, as a result of mental overstrain or insufficient mental load and stress, which arise from the nature of the work, control or maintenance of the machine. The main group of hazards in the working environment arises when working without or with incorrect use of personal protective equipment. Another group of hazards is associated with the conditions of the working environment, such as insufficient lighting of the specific workplace, inappropriate construction, location and recognition of controls or means of presenting information.

Combined hazards – the combination of various hazards from the aforementioned groups and their joint impact creates a hazard with a high degree of risk [8, 9].

The determination of hazards in the working and surrounding environment is applied and is the subject of research in production systems and in the field of technical, fire, emergency, explosion and other types of safety. The authors imply into the concept of 'hazard' a meaning and content that they adapt mainly to their capabilities for collecting and processing data. Both many common

characteristics of the introduced terms and many differences have been established. In a number of cases, some imaginary meaning is implied. This leads to idealised and unrealistic definitions. The result is inadequate assessments, non-objective understanding of the 'mechanism' of emergence and development, and hence ineffective protective activities.

III. RESULTS AND DISCUSSION

Occupational and environmental factors in industrial enterprises are systematically presented in the following figures. Hazard, as well as safety, can exist in specific real systems – production, ecological, ergonomic, domestic, etc. [10, 11].

Figure 1 presents a model for the systematic presentation of an industrial enterprise, with the hazards contained therein.

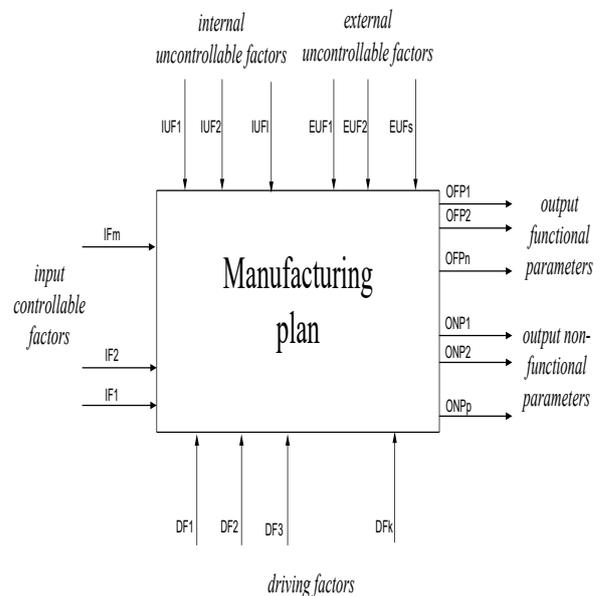


Fig. 1 Systematic presentation of an industrial enterprise.

Each production system operates in the conditions of a specific occupational and surrounding environment and can be represented by a generalised cybernetic scheme – Fig. 1. In it, the control object is characterised by a large number of input control disturbing factors and output parameters.

The factors and parameters can be combined into the following sets:

- *Set of input controllable factors enabling the operation of the production enterprise (IF), $IF = \{IF_i\}; i=1, m$, which unites factors such as input materials, energy, information and the like.*

They determine the nature of the processes and can be continuously or periodically controlled. Information about their current values is obtained objectively (through control and measuring devices), subjectively (through laboratory analysis, calculations, etc.) and indirectly (by results of other measurements and factors).

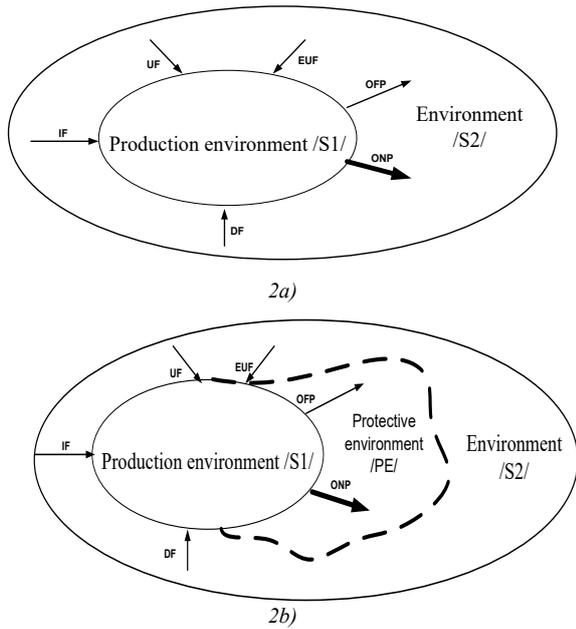


Fig. 2. Hazard (risk factors of occupational and surrounding environment) (a) and protection measures (b).

- *Set of driving factors (DF), $DF=\{DF_{ij}\}; i=1, k$, which includes the quantities the target change of which supports a certain mode of operation of the production system. Related to organising the technological production process.*
- *Set of internal uncontrollable factors of the occupational environment (IUF), $IUF=\{IUF_{ij}\}; i=1, l$, i.e. all uncontrollable impacts that change the normal production process. They include risk factors such as technical breakdowns, accidents, incidents, etc.;*
- *Set of external uncontrollable factors of the surrounding environment (EUF), $EUF=\{EUF_{ij}\}; i=1, s$, i.e. all uncontrollable impacts related to natural phenomena and processes (earthquakes, floods, external radioactive, electromagnetic and noise pollution) which change the normal production process.*
- *Set of output functional parameters (OFF), $OFF=\{OFF_{ij}\}; i=1, n$, which unites controllable values determining the quantity, composition and quality of production. This set characterises the main function of the system. These parameters are called functional or functional outputs.*
- *Set of output non-functional parameters harmful to the external environment (ONP), $ONP=\{ONP_{ij}\}; i=1, p$, this set characterises parameters that do not determine the main function, but are its derivative – type and characteristics of waste, environmental impacts, impacts on other production systems with risk factors, etc.*

When defining the hazard, the interaction of production systems with the working and surrounding environment or with other systems is taken as a basis.

System S_1 (Figure 1) is a production system at an industrial enterprise. S_2 (Figure 2a) is the system of its

environment, which can be natural, artificial, urban, other production (human-machine) systems, etc.

The environment S_2 is safe when the output impact factors (functional and non-functional parameters) created by the production system S_1 do not create hazards.

Provided that the output impact factors (functional and non-functional parameters) created by the production system S_1 cause hazards in the system S_2 (Figure 2a), it is necessary to create the so-called protective environment PE (Figure 2b) designed to limit, localise and stop their hazardous action. Examples of the construction of protective environments are the installation of purification equipment, filters, screens, fences, etc.

The integral hazard G at an actual operating production enterprise, written in tuple form, will be:

$$G = \{[G_1]; [G_2]; [G_3]\} = [P(C)]; [P(S)]; [U] \quad (1)$$

where:

- G_1 is a differential hazard of the first kind and represents the possibility P of the occurrence of a phenomenon C with a harmful effect S :

$$G_1 = [P(C)] \quad (2)$$

- G_2 is a differential hazard of the second kind which describes the probability that the on-going hazardous phenomenon C has a harmful effect S and causes damage U :

$$G_2 = [P(S)] \quad (3)$$

- G_3 is a differential hazard of the third kind and denotes the degree and type of harm as well as the severity of the damage caused U .

When damage U occurs, the actions aim at maintaining it at a possible low level or avoiding secondary consequences – rescue, medical assistance, treatment, etc. In this case, an attempt is made to limit the number of evaluation indicators and the intensity of damage development. These actions are compensatory actions.

As a result of the presented analysis of the term ‘hazard’, the safety SI of production systems, as an alternative, can be formally described as follows:

$$SI = 1 - \{G\} = 1 - \{[P(C)]; [P(S)]; [U]\} \quad (4)$$

Therefore, the task of safety SI in production systems is reduced to the search for solutions in which

SI - max, a G - min, which shows that the safety analysis is reduced to the analysis of the hazard.

Based on the presented logical and methodological arguments, a research morphological model of hazards is presented (Figure 3).

The purpose of the presented morphological model is the possibility of the process of determining the hazard to be transformed from a hazardous phenomenon into a hazardous effect (damage):

- the differential hazard of the first kind G_1 represents a hazardous phenomenon;
- the differential hazard of the second kind G_2 – a hazardous action;
- the differential hazard of the third kind G_3 – a hazardous effect.

Each of the differential hazards is characterised by its indicators shown in Figure 2.

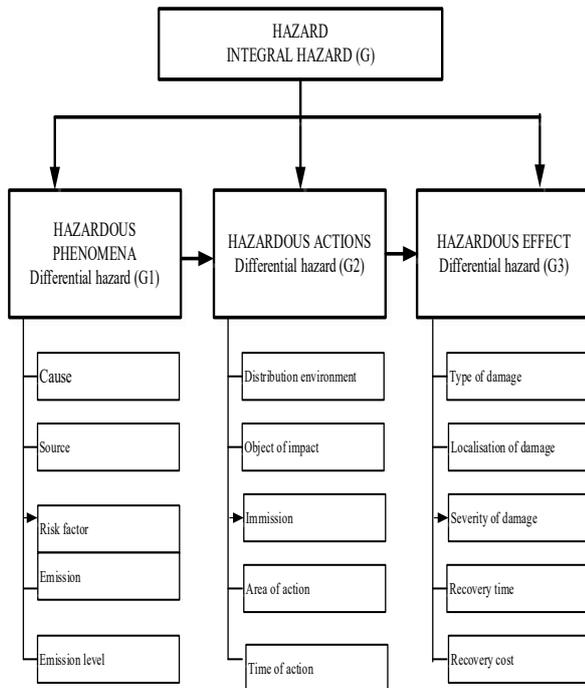


Fig. 3 Morphological model of hazard in industrial enterprises.

The process of building a morphological model for determining hazards in the occupational and surrounding environment of industrial enterprises goes through the following stages:

A. First stage: Defining hazards of the first kind G_1 represents a hazardous phenomenon.

At this stage, cause-and-effect relationships and sources of hazard are sought in the operating mode of the enterprise. It is possible to use a ranking of hazards according to their probability.

Sources of hazard in industrial enterprises are the technological operations performed. These are manual machines and tools with hot and cold surfaces, machines for pressing, stamping and drawing, flow machines with fast-moving elements, etc. The implementation of certain operations is the cause of the appearance of hazard in the ergonomic system.

The sources of hazardous phenomena are the technological equipment in a given workshop and its interaction with the subjective factor (operators of machines, facilities and equipment), which leads to the generation of risk factors.

The main indicator of hazardous phenomena is the presence in production processes of risk factors related to physical, chemical and biological impact.

Physical risk factors include:

- exposed and moving parts of machines;
- sharp edges and rough surfaces of workpieces;
- tools and tooling (stamps, dies, templates, etc.);
- conventional heat radiation from heated surfaces of workpieces and products;
- noise generation from mechanical hammers (pneumatic and hydraulic), hydraulic presses, transport and lifting equipment, aspirating and heating air systems;
- light radiation from the surface of workpieces and semi-finished products;
- sparking in the process of burning microparticles, through oxidation during plastic processing of surface-heated workpieces;
- electromagnetic fields created by induction and hardening machines;
- devices using the effect of absorbing ionizing radiation [9] – devices for technological control such as radiation level gauges, thickness gauges, densitometers, etc.

Chemical risk factors [12] are classified according to the nature of their impact on human physiology, more precisely:

- irritating and toxic chemical substances released during the use of conventional fuels – coal, coke, fuel oil, petroleum.
- harmful chemical substances released during evaporation from oil and salt baths and during heat treatment of blanks and parts.

Psychophysiological risk factors, according to the way they affect a person, can be defined as:

- neuropsychic overloads associated with the complex action of various factors of the production environment;
- physical overloads, a consequence of specific operations performed by the subject in production.

In the working and environmental conditions of industrial enterprises, risk factors are the generation of noise, vibrations, heat, light and radioactive radiation, the spread of electromagnetic waves. They must be additionally assessed, depending on the degree of impact (the amount of their emission into the environment).

Emission is one of the indicators of differential hazard of the first kind. There are two categories of emissions – functional and emergency. Each emission is characterised by a level of quantitative indicator. The level of emission in the working and surrounding environment is subject to ranking and determining the impact according to the regulatory limits of biological impact.

A hazardous phenomenon develops into a hazardous action when at the moment of its occurrence, there is an impact on the object or subject of the ergonomic system.

B. Second stage: Assessment of the environment of distribution of the hazardous impact.

The indicator of distribution environment is associated with the contact of the object and the subject with the hazardous impact. In industrial enterprises, two distribution environments are defined – working and surrounding. The first environment is defined as the workplace which provides optimal conditions for the functioning of the ergonomic system. The surrounding environment includes the working area, the workplace, the work room or the boundaries of the production enterprise.

The object on which the hazardous phenomenon acts is the object of impact and is the main indicator characterising the hazardous action. In industrial enterprises, the object of impact is the working personnel, machines, facilities and technical equipment.

Immission is an indicator of the hazardous action and is the result of the emission of a specific risk factor at a certain point in the working area, the workplace or the boundaries of the production enterprise. Immission as an indicator of the hazard has qualitative and quantitative characteristics. Qualitative characteristics are determined by the type of impact (chemical, radiation, noise, etc.). The emission level is a quantitative characteristic of the intensity of the impact and, accordingly, a quantitative indicator for a certain point of the working and surrounding environment.

The indicator of space and action is limited in industrial enterprises, this is the area of production and storage of finished products. The time of the hazardous action is a crucial indicator for the scale of distribution and the damage caused. It is correlated with the concentration of the emission at a certain point of the working and surrounding environment.

C. Third stage: Determination of the final effect of the hazard on the working and surrounding environment.

The course of the hazardous action ends with the occurrence of a hazardous effect. When ranking the indicators by degree of significance, the type of damage is dominant. It is quantitatively measurable with the material, economic and health damage caused. Material damage is characterised by the degree of damage and is associated with the occurrence of malfunctions, breakdowns and accidents of technical equipment. Health damage is characterised by a diagnosis, temporary incapacity for work and disability to varying degrees. Health and material damage are interrelated and lead to a decrease in the economic efficiency of production.

Localisation, as an indicator, characterises the specific place of occurrence of the hazardous effect. It is characterised by the numerical value of the area and volume of distribution of the damage.

Recovery time, as an indicator of hazardous effects, is relatively related to the object and subject of impact and

depends on the degree and nature of the impact on the working and surrounding environment in the industrial enterprise.

IV. CONCLUSIONS

The indicated morphological model for determining hazards in the working and surrounding environment uses information that can help to determine all risk factors that affect the given system – production, environmental, domestic. The universality of its application is dictated by the consideration of actually existing environmental factors and the transformation of the hazardous phenomenon into a hazardous effect.

The implementation of a thorough analysis of risk factors in a system is decisive for its efficiency and operability. The construction of a morphological model in the process of determining hazards (risk) and the associated characterisation of the sources and cause-and-effect relationships for their occurrence is a guarantee for increasing environmental safety.

When analysing the aetiology of all hazards (risk factors), it is necessary to take into account and build a protective environment to ensure and guarantee the safety of the functioning of the environment under consideration.

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