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Foundations of Multi-Factor Parametric Modeling for the Occupational Safety Management System in Industrial Enterprises

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Abstract

This article examines the significance of hazard identification and risk assessment in ensuring effective labor protection in industrial enterprises, emphasizing their central role in preventing occupational incidents and improving safety management. It aims to clarify the content and essence of hazard identification, explain how systematic identification underpins robust risk assessment, and outline methodological approaches for determining the full set of hazards and their parameters. Adopting a systems-analysis perspective, the article describes how multi-factor experimental design and systematization methods can be applied to capture the interaction of multiple variables and to structure complex hazard information in industrial settings. The discussion highlights that the combined use of these methods enables a more comprehensive and precise mapping of hazards and their characteristics, thereby strengthening the reliability of risk assessments and supporting evidence-based decisions in labor protection. The article concludes that integrating hazard identification with multi-factor and systemic analytical approaches offers a methodological foundation for enhancing occupational risk management and refining safety strategies in industrial enterprises.

Keywords: Labor Protection; Hazard Identification; Risk Assessment; Industrial Enterprises; System Analysis

Introduction

At present, great attention is being paid in industrial enterprises to systematization, organization of systematic management, modeling, and evaluation of the complex of hazards in effective management of labor protection. For this purpose, it is required to describe the relationships between external and internal factors and system components, to develop universal sets of factor parameters and relationships, and to study a generalized technical system of the type "Factors–Object–Protection–Worker" (FOPW).

In solving these issues, it is necessary to use regulatory documents such as the "Hazard Identification Register", "Occupational Safety Management System. Methods for Identifying Hazards at Various Stages of Work", and "Occupational Safety Management System. Methods for Risk Assessment in Ensuring Work Safety" based on the requirements of international standards.

Methods

The research uses literature review, analytical, predictive, comparative, and statistical analysis methods, as well as surveys, observations, analysis of open ideas, and experimental test results.

Results and discussion

Identification is the process of determining the hazard and its quantitative and temporal indicators, as a result of which preventive and operational measures aimed at ensuring life safety are developed. During the identification process, the nomenclature of hazards, the probability of occurrence, spatial coordinates ("localization"), expected damage, and other parameters are determined. Based on the obtained results, specific measures are developed.

The hazard has a potential, that is, a hidden nature. Therefore, in ensuring life safety, the early identification of hazards plays an important role. The conditions under which a potential hazard arises and is realized are called the causes of accidents. Accidents can be of various types — injuries, damage, diseases, and other forms.

Hazard, cause, and consequence are the main characteristics of accidents, emergencies, fires, and other undesirable events. “Hazard–Cause–Undesirable Consequence” is a logical development process that leads to the manifestation of a hidden hazard and causes real damage. As noted, this process is multi-causal. Therefore, identifying the causes of accidents plays an important role in preventing them.

Examples related to “hazard–cause–consequence”: Electric current (hazard) – short circuit (cause) – burn (consequence); Pesticides (hazard) – not using PPE (cause) – poisoning (consequence).

Any human activity is a potentially dangerous process. Although this statement is axiomatic, it has important methodological significance.

System analysis is a set of methodological tools used to prepare and justify decisions on complex problems, including safety systems. A system is a set of interconnected components, and as a result of their interaction, a certain goal is achieved, i.e., work is performed. The components of the system include not only materials and objects but also their interrelations and relationships.

Any well-functioning machine can serve as an example of a technical system. If a human constitutes one of the components (elements) of a system, such a system is called an ergatic system. Examples of ergatic systems include “human–machine,” “human–environment,” and “human–machine–environment.”

The main purpose of system analysis of safety is to identify the causes leading to accidents and to develop appropriate and economically efficient measures to prevent them.

Any human activity takes place within a certain system, for example, within the “Human–Machine–Environment” system. All elements forming this system have their own specific features, characteristics, reasons that cause hazardous factors, and levels of interaction. If any one element fails to perform its function, the operation of the system is disrupted.

For example, the "operator–computer–electric current" forms a single system. If one of these elements is missing, the work will not be performed. Each element of the system has its own function, as does the system as a whole. When analyzing the system, the causes of accidents in each element are studied first.

For example, in this ergatic system: the human (operator) controls the computer, monitors processes, and gives commands to the computer. The operator must be sufficiently qualified and fully understand the rules of safe computer operation. Therefore, the operator must first be trained in the rules for safe operation of these technical tools and in methods of protection from hazardous and harmful factors, and his or her knowledge must be tested.

The computer executes the commands given by the operator. For this, the main parameters of the computer must correspond to the indicators of the technological process, and hazardous and harmful factors (radiation, noise, etc.) must be within permissible limits. Electric current supplies energy to the entire system and must be installed safely to prevent the operator from being exposed to electric shock.

After identifying the causes of accidents in all elements, the hazards that may arise under their influence are analyzed. Then the consequences of these hazards are determined, and a "Cause–Hazard–Consequence" tree (table) is constructed. Based on the "Cause–Hazard–Consequence" analysis, a plan of preventive measures to avoid accidents is developed.

In addition to the specific properties of its elements, the system itself has its own characteristics. The property that arises in the system does not exist in any of its individual elements. For example, "flammable substance–oxygen–source of ignition" form a single system. If any of these elements is absent, the combustion process will not occur. Here, the flammable substance has the property of burning, oxygen has the property of creating the conditions for fire, and the source has the property of initiating the fire. The absence of any of these elements leads to the destruction of the system, and the intended result (in this case, combustion) does not occur.

The main purpose of system analysis for safety is to identify the causes leading to undesirable consequences (accidents) and to develop measures that ensure the reduction of their likelihood.

The“cause and hazard tree” system.

Any hazard arises as a result of certain causes and leads to undesirable consequences. There can be no real hazard without a cause. Therefore, eliminating or preventing a hazard primarily depends on studying its origin, which is explained through a “cause-and-effect” relationship.

A hazard, as the result of one or several causes, can also become the cause of another hazard. That is, a hazard arising under the influence of one cause can lead to another hazard, and that hazard, in turn, can give rise to yet another, resulting in a hierarchical, chain-like, or systemic connection. The graphical representation of such a relationship resembles a multi-branched tree.

Therefore, in some literature devoted to safety analysis, terms such as “Cause Tree,” “Fault Tree,” “Hazard Tree,” and “Consequence Tree” are often used. Of course, in such graphical expressions (“trees”), there are branches of causes and branches of consequences, showing the full dialectical nature of the “cause-and-effect” relationship. For this reason, it is more appropriate to call such graphical representations a “Tree of Causes and Consequences.”

Constructing such “trees” is one of the main stages of identifying the causes of undesirable events. Since the branching of the tree is a multi-stage, infinite process, certain limitations must be established. These limitations depend on the purpose of the study and must be logically justified.

As noted above, in hazard assessment, determining the level of risk plays an important role. “Risk” is the frequency of occurrence or realization of a hazard, that is, the quantitative criterion for hazard evaluation.

“Risk-taking” means acting against danger. “Risk” is the frequency of occurrence of a hazard — the quantitative measure of danger.

Quantitative assessment is the ratio of undesirable consequences that occur during a certain period of activity to the expected hazard or outcome.

$$R_{ur} = \frac{n}{N};$$

n – the number of workers who died in production during the year;
N – the total number of workers.

Risk, depending on the type of hazard, is divided into individual and social types. Individual risk characterizes the danger directed at a single person, while social (more precisely, group) risk describes the danger that affects a group of people.

During activity, when comparing risk—i.e., exposure to danger—and the results of the activity (benefit), many specialists propose applying a monetary measure of human life. Of course, not all experts support this approach. However, if the question is posed as *"How much money should be spent to save a human life?"*, then such a proposal can be considered appropriate. According to studies conducted by several foreign researchers, the value of human life and safety can range from 650 thousand to 7 million US dollars.

The procedure for determining risk is largely approximate and can be divided into the following four methods:

- Engineering method. This method is based on statistical data, calculation of hazard frequency, probabilistic safety analysis, and construction of fault trees.
- Modeling method. In this approach, models of hazardous and harmful factors affecting individuals or groups of people are developed.
- Expert method. The probability of various incidents is determined based on the opinions and judgments of experienced specialists (experts).
- Sociological survey. Here, the probability of incidents is determined through the opinions and perceptions of the general population.

The above-mentioned methods reflect different aspects of risk. Therefore, in practice, it is advisable to apply these methods in a comprehensive manner.

Conclusion

Based on risk assessment, industrial enterprises must:

- Collect objective information about working conditions, existing hazards, and the degree of their impact on workers;
- Identify the weakest aspects of occupational safety, develop hazard management measures, and create opportunities to ensure reliable worker protection;

- Develop and implement preventive and regulatory measures for protecting workers from hazards in accordance with the priority order specified in Clause 4.10.1.1 of GOST 12.0.230.

Within the occupational safety management system, 28 types of hazards and 154 parameters related to them have been identified in industrial enterprises. Considering the officially published sets of hazard types and their parameters, it is recommended to use the multi-factor parametric basis method in evaluating safety indicators and risk levels.

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