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ІНТЕГРОВАНИЙ ПІДХІД ДО МОДЕЛЮВАННЯ ТА ЗМЕНШЕННЯ РИЗИКІВ У СИСТЕМІ УПРАВЛІННЯ ОХОРОНОЮ ПРАЦІ ПІДПРИЄМСТВ ТРАНСПОРТНОЇ ГАЛУЗІ

INTEGRATED APPROACH TO RISK MODELING AND MITIGATION IN THE OCCUPATIONAL SAFETY MANAGEMENT SYSTEM OF TRANSPORT INDUSTRY ENTERPRISES

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Abstract. The article analyzes modern approaches to occupational safety management at transport enterprises, taking into account the latest challenges, risks and trends. The need for systematic identification and assessment of risks arising in the process of production activities of transport enterprises is substantiated, taking into account the specifics of technological processes and hazard factors. Mechanisms for combining

occupational safety standards, environmental management and quality management systems into a single integrated system are proposed to increase the level of personnel safety and reduce production risks. Particular attention is paid to the application of preventive measures, monitoring and continuous improvement of safety procedures. The implementation of an integrated approach allows ensuring the sustainable development of transport enterprises, reducing the likelihood of emergency situations and increasing the effectiveness of management decisions in the field of occupational safety**.**

The object of research is the occupational health and safety management system at transport industry enterprises.

The purpose of the work is to substantiate and develop an integrated approach to risk management in the occupational health and safety management system at transport enterprises in order to increase the level of employee safety, reduce production risks, and ensure sustainable development of the enterprise.

Research methods - analytical.

Modern and high-quality management of labor protection at enterprises is one of the priority areas of enterprise activity in terms of reducing industrial injuries, improving working conditions and improving the microclimate at the enterprise. In order to effectively manage labor protection at enterprises of the transport industry, the authors of this article propose to introduce a new modern model of the labor protection management system based on a strategy for preventing the occurrence of hazards and risks at workplaces. The purpose of the study is to determine the correct approach to organizing the labor protection system at enterprises of the transport industry through an integrated approach to risk management, as well as modeling the process of improving the state of labor protection at enterprises.

The results of the research can be recommended for implementation in the occupational safety management system at enterprises of Ukraine.

Keywords: risk-based management, occupational health and safety, transport, occupational safety, production process, model, methodology, digital technologies, identification, optimization.

Problem statement.

Modern transport enterprises operate in highly dynamic industrial environments, where rapid technological changes and organizational transformations create significant risks for personnel. Despite the increased requirements for occupational safety, the level of injuries and accidents in the transport industry remains a pressing problem. One of the key challenges is the lack of effectiveness of traditional approaches to risk management, which are based mainly on rapid measures after incidents occur, rather than on systematic forecasting and prevention of potentially dangerous situations. In such conditions, an important task is the development of models that allow for rapid and accurate risk assessment, forecasting their dynamics and implementing effective measures to reduce them. Thus, the research problem is the need to create integrated approaches and models for systemic risk management in occupational safety at transport enterprises, which allow minimizing the likelihood of accidents and ensuring the sustainability of production processes in dynamic industrial environments.

Analysis of recent research and publications. Analysis of scientific research shows that the issues of modeling and risk management in occupational safety are actively studied both in Ukraine and abroad. Domestic scientists V.A. Tsopa, S.I. Cheberyachko, O.O. Yavorska, O.V. Deryugin, A.P. Bochkovsky and others [1-5] investigate the features of assessing occupational risks in the transport sector and propose integrated approaches to their reduction. Foreign authors S. Ismael, J. Chen, Y. Zhang, A. Tewari, A. Paiva [6-9] focus on creating dynamic and probabilistic models that allow predicting hazardous production situations in a changing environment. The works substantiate the feasibility of using system dynamics, Bayesian methods and computer modeling to increase the effectiveness of risk management. At the same time, the issue of integrating such models into occupational health and safety management systems of transport enterprises remains understudied, which determines the relevance of further research in this area.

The purpose of the article is to substantiate and develop approaches to the comprehensive implementation of the risk management process in occupational safety management systems of transport enterprises. To achieve this goal, the following tasks are planned: to analyze modern scientific approaches to

assessing occupational risks, to determine the features of their manifestation in the dynamic conditions of the transport industry, to investigate the impact of industrial hazards on the level of occupational safety, to develop risk management models, and to formulate practical recommendations for improving the occupational safety system and reducing the likelihood of dangerous situations.

Presentation of the main material.

The most effective, recognized in the world strategy for ensuring and maintaining the highest possible level of occupational safety and health is the strategy for preventing the occurrence of hazards in the workplace. It involves the development of safety precautions based on the procedure for assessing the relevant risks. This strategy is the foundation of the regulatory and legal framework for occupational safety in developed countries of the European Union and is constantly revised taking into account modern problems of protecting workers from accidents and occupational diseases.

Within the framework of the Association Agreement with the European Union, Ukraine has undertaken the obligation to gradually, over several years, reform its own legislative framework by implementing and harmonizing relevant regulatory acts. Thus, during the specified period, all business entities, without exception, must automatically adopt a fundamentally new for many risk-oriented strategy for ensuring comfortable, safe and healthy working conditions.

One of the first steps towards such a transition was the adoption of the Concept of reforming the occupational safety and health management system in Ukraine and the development of a draft of the new Law of Ukraine "On Occupational Safety and Health of Employees", which has been submitted for public review and discussion and is to replace the current Law of Ukraine "On Occupational Safety and Health" [10]. The provisions of the Concept and the requirements of the new law provide for the creation of fundamentally new occupational safety and health management systems (OSHMS) at enterprises, the functioning of which is based on the principles of managing the risks of occupational hazards (Article 8 of the draft Law) [11]. To this end, business entities must carry out risk assessment procedures at each workplace and develop and implement appropriate safety measures and means based on the results of such an assessment.

The danger of the transport industry is due to the increased dynamism of production processes, a high level of mechanization, the operation of complex equipment and the influence of the human factor. Transport is a high-risk area, where any deviations from technological standards or non-compliance with safety rules can lead to significant material damage, injuries or even death. Of particular difficulty is the multi-level interaction of people, technology and the environment, which requires an integrated approach to risk management and occupational safety.

When studying occupational safety issues, special attention should be paid to the specifics of the transport industry, which covers a wide range of activities - from freight and passenger transportation to vehicle maintenance, infrastructure work and logistics operations. Each of these areas has its own set of potential hazards: mechanical, electrical, ergonomic, chemical and psychophysiological risks. Thus, in road transport, the main risk factors are high speed, heavy traffic, driver fatigue and the human factor, while in rail or air transport, technological risks associated with the operation of complex equipment dominate.

It is important to note that the transport industry is not only a high-risk, but also a socially significant sphere, since the functioning of the state economy depends on its stable operation. Therefore, increasing the level of occupational safety in transport enterprises is not only of production, but also of strategic importance. The introduction of risk-based occupational safety management systems will contribute to the reduction of occupational injuries, the increase of safety culture and the strengthening of the reputation of the industry as a whole.

In order to form a risk-based occupational health and safety management system (OHSMS) at transport enterprises, it is first necessary to introduce systematic hazard identification, risk assessment, and development of preventive measures to reduce or eliminate them.

The implementation of occupational risk assessment is aimed at implementing a continuous process:

– identifying new hazards that are present or may appear during production activities, and monitoring already identified hazards;

– determining the probability of hazards occurring and predicting the possible consequences of their impact on the employee;

– managing occupational risks in order to reduce their magnitude.

Hazard identification, assessment and management of occupational risks in the field of occupational safety is carried out:

– by type of work;

– at the workplace.

An integrated model of risk assessment and management stages at transport enterprises is presented in Figure 1.

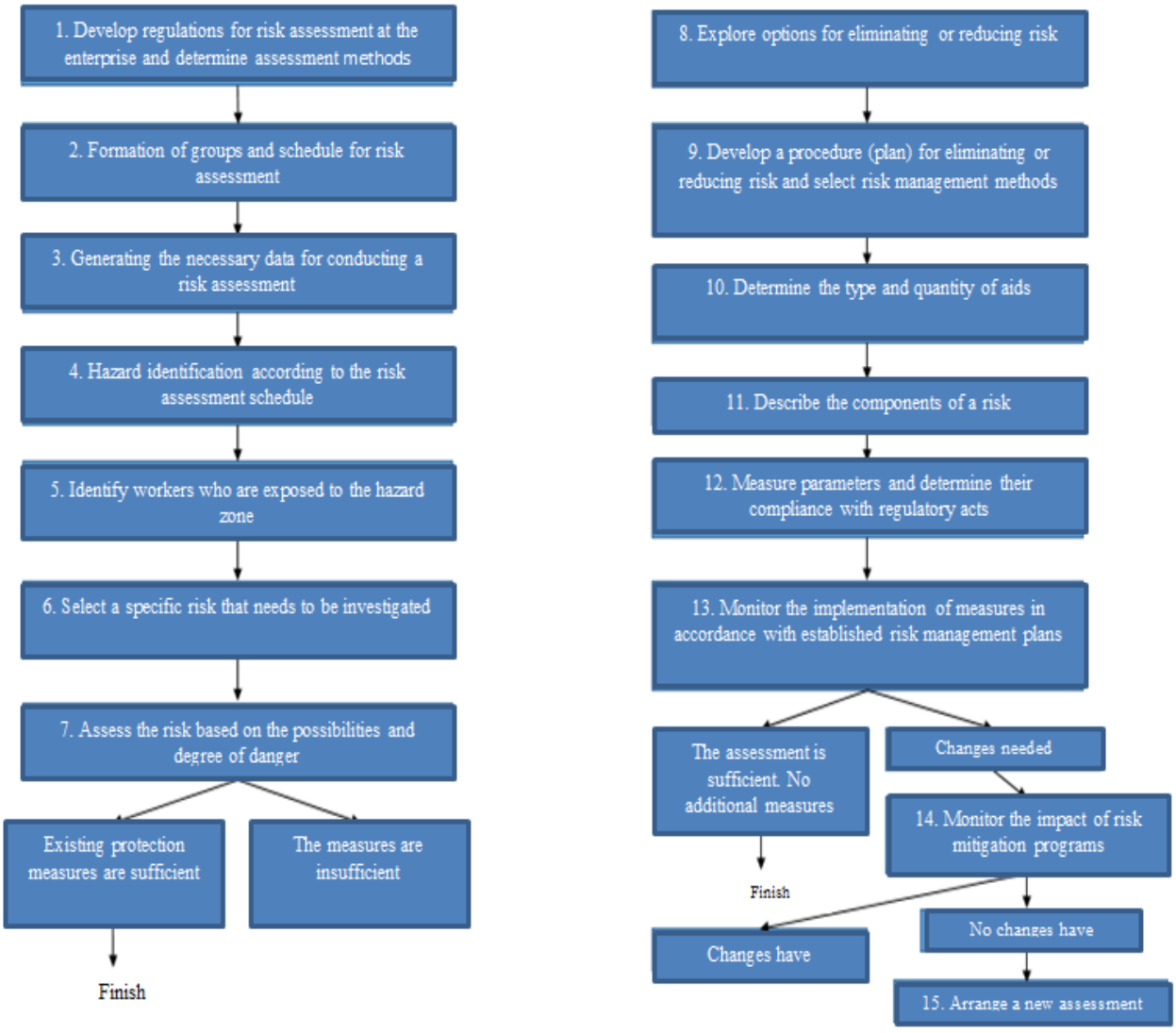

Figure 1 – Stages of risk assessment and management at transport enterprises

Рисунок 1 – Етапи оцінки та управління ризиками на транспортних підприємствах

Hazard identification, assessment and management of occupational risks is based on the "consequence/probability matrix" method in accordance with DSTU IEC/ISO 31010 [12].

The obtained results of occupational risk assessment are recommended to be used:

– during training and instructions on occupational safety, internship (duplication) of employees to inform the latter about the results of occupational risk assessment at their workplaces;

– during the preparation of technological maps;

– in work performance projects;

– in occupational safety instructions or instructions for the operation of equipment, facilities, devices, etc.;

– during the preparation of production plans and occupational safety work plans;

– planning measures to improve working conditions (making changes to technological processes, replacing equipment, etc.);

– during the analysis of the causes of accidents at work [13].

For each identified hazard, an assessment of the occupational risk that this hazard poses to workers is carried out.

The "consequence/probability matrix" method is used to assess occupational risks. According to this method, for an identified hazard, the following is determined:

– probability of occurrence of the hazard (P);

– severity of the consequences of the hazard (S) on the worker;

– magnitude of the occupational risk (R) from the hazard;

– significance category of the occupational risk posed by this hazard.

The probability of occurrence of a hazard (P) is determined by one of two methods:

- if there is information about the frequency of its impact on employees (statistics of occupational injuries of the unit) regarding the identified hazard, then the probability (P) is determined according to Table 1:

Table 1 – Assessment of Hazard Occurrence Probability (P) Using Quantitative Indicators

Таблиця 1 – Оцінка ймовірності виникнення небезпеки (P) за допомогою кількісних показників

Probability of danger		*Number of occupational injuries resulting from exposure to identified hazards on workers*
Value P, points	*probability notation*	
1	minimal	0 in the last 5 years
2	moderate	1-2 in the last 5 years
3	significant	3 in the last 5 years
4	significant	4-5 in the last 5 years
5	very high	more than 5 in the last 5 years

- if there is no information regarding the frequency of its impact on workers for the identified hazard, then the probability (P) is determined subjectively, based on one's own experience and taking into account Table 2:

Table 2 – Assessment of Hazard Occurrence Probability (P) Using Qualitative Indicators

Таблиця 2 – Оцінка ймовірності виникнення небезпеки (P) за допомогою якісних показників

Probability of danger		*Qualitative characteristics of the occurrence of danger*
Value P, points	*probability notation*	
1	minimal	The probability of the hazard occurring is insignificant (under existing production conditions, an incident with consequences is unlikely to occur).
2	moderate	The probability of a hazard occurring remains low (under existing production conditions, the occurrence of an incident with consequences is at a low level).
3	significant	The probability of the hazard occurring is at an average level (under existing production conditions, an incident with consequences may occur suddenly).
4	significant	The probability of the hazard occurring is high (under existing production conditions, an incident with consequences is likely to occur).
5	very high	The probability of a hazard occurring remains very high (under existing production conditions, an incident with consequences will definitely occur).

To determine the probability of occurrence of a hazard (P), preference should be given to the method based on quantitative characteristics (Table 2).

The severity of the consequences of the identified hazard on workers (S) is determined according to Table 3.

Table 3 – Assessment of the Severity of Consequences of a Hazard

Таблиця 3 – Оцінка тяжкості наслідків небезпеки

Consequences of exposure to danger		*Description of possible consequences of the hazard*
value S, points	*severity designation*	
1	minimal	case without loss of work capacity
2	moderate	accident with "short-term" loss of ability to work (up to 15 days inclusive)
3	significant	- accident with "long-term" loss of working capacity (more than 15 days); - case of occupational disease of an employee;
4	substantive	- accident with a disabling consequence; - group accident without a fatal consequence; - group case of an occupational disease without serious or fatal consequences
5	catastrophic	- fatal accident; - group accident, including one fatal accident; - case of occupational disease resulting in serious or fatal consequences

When determining the severity of the consequences of a hazard (S), it is necessary to take into account:

– the amount of potential harm to the employee (significant or insignificant);

– human consequences (number of people who may be affected);

– the ability of the hazard to recur or its absence (a one-time manifestation of the hazard or the hazard has the property of being repeated);

– the duration of the hazard exposure (short-term or long-term).

Based on the results of determining the probability of occurrence of the hazard (P) and the severity of the consequences of its impact (S), the value of the occupational risk (R) carried by this identified hazard is calculated [14]:

$$R = P \times S\,, \tag{1}$$

where R – professional risk value, points;

P – probability of danger occurrence, points;

S – severity of the consequences of the hazard, points.

Based on the result of calculating the value of the occupational risk (R), using the matrix of consequences/probabilities (table 4), the significance category of the obtained occupational risk is determined (table 5):

– low occupational risks (R = 1..5);

– moderate occupational risks (R = 6..12);

– significant occupational risks (R = 13..25).

Table 4 – Consequences–Probability Matrix (Occupational Risk Value (R))

Таблиця 4 – Матриця наслідків та ймовірностей (значення професійного ризику (R))

Probability of occurrence of hazard (*P*) / Severity of the consequence of the hazard (*S*)	1	2	3	4	5
1	1	2	3	4	5
2	2	4	6	8	10
3	3	6	9	12	15
4	4	8	12	16	20
5	5	10	15	20	25

Table 5 – Categories of Occupational Risk Levels
Таблиця 4 – Категорії рівнів професійного ризику

Color coding of occupational risk significance categories and corresponding occupational risk values (R)	*Name of the category of significance of occupational risks*	*Description of the significance category of occupational risks*
1..5	low occupational risks	- occupational risks that do not pose a potential threat to the life or health of the worker; - occupational risks are considered "acceptable"; - it is sufficient to warn the worker about the presence of occupational risks that pose a danger
6..12	moderate occupational risks	- occupational risks that pose a potential threat to the life or health of the employee; - occupational risks are considered "acceptable provided" simple measures are taken to manage them (warning signs, fencing, use of PPE); - occupational risks require constant monitoring and analysis
13..25	significant occupational risks	- occupational risks that pose a threat to the life or health of the worker; - occupational risks are considered "unacceptable"; - work is not permitted until the management of occupational risks has made the work and workers safe

Based on the results of the occupational risk assessment, the relevant information is entered into the occupational risk card, namely:

– probability of occurrence of danger (P) in points;
– severity of consequences of exposure to danger (S), in points;
– magnitude of occupational risk (R), in points;
– category of significance of occupational risk (low/moderate/significant occupational risk).

After assessing the occupational risk and determining its significance category, occupational risk management is carried out (selection and implementation of appropriate measures) in order to reduce the significance category of this risk.

First of all, significant and moderate occupational risks require management. Occupational risk management is implemented by:

– changing the probability of occurrence of the hazard (P);
– changing the severity of the consequences of the hazard (S);
– simultaneously changing the probability of occurrence (P) and the severity of the consequences of the hazard (S).

When choosing measures for occupational risk management, it is necessary to strive to reduce the magnitude of the occupational risk (R) taking into account the following hierarchy (from more effective measures to moderate):

– complete elimination of the hazard: replacement of hazardous equipment (equipment, devices, etc.) with safe ones; replacement of harmful materials with harmless ones; change of work technology, in order to eliminate a certain hazard;

– reduction of the magnitude of the occupational risk from the hazard: making changes to the technological process (use of less harmful materials, reduction of voltage level; replacement of equipment,

equipment with one that has a lower level of danger, harmfulness); replacement of the existing hazard with another, with a reduced level of significance category;

– prevention of employee contact with the hazard: removal of the employee from the zone where the hazard is present or application of appropriate technical solutions (installation of ventilation, fencing, insulation);

– application of safe work performance systems: use of a system for visualizing information about hazards (safety signs and markings, warning posters); conducting training and briefings on labor protection issues; conducting internships (duplication); application of a system of work permits (orders) for work associated with occupational risks; monitoring the condition of equipment, etc.;

– application of protective equipment: use of collective and individual protective equipment [15].

Occupational risk management measures that require additional actions from the employee are less reliable than those that are carried out without his participation. For example, warning an employee about the prohibition of entering the danger zone is a less effective measure than fencing off the dangerous place, as a result of which the employee's access to the danger will be blocked.

If several occupational risk management measures are identified, then the most effective among them can be assessed according to the following criteria:

– by the magnitude of the change in the level of danger: the more the value of the occupational risk is reduced, the more effective the measure will be;

– the area of impact of the measure: the more occupational risks are affected by the measure or the safety of the more people it has an impact on, the more effective this measure will be;

– compliance with safety standards: if the measure will bring the conditions and safety of work into compliance with the requirements of regulatory legal acts on labor protection, this measure must be applied;

– effectiveness of the measure and costs: a measure that ensures the reduction of occupational risk to an acceptable level at moderate costs is considered more effective than a measure to completely eliminate the hazard through significant financial (material) costs or a complete change in production technology.

After determining the measures for managing occupational risk, it is necessary to enter the relevant information into the occupational risk card, namely:

– information on the identified measures for managing occupational risk;

– the position of the person supervising the implementation of the measures;

– the deadline/terms for implementing the measures (if necessary).

To implement occupational risk management measures, it is necessary to plan their implementation, for which:

– identify measures that require priority resolution;

– if there are several measures to resolve one issue, choose the optimal one in terms of occupational risk management and the costs (resources) required for this;

– determine the sequence of implementation of measures;

– identify measures that must be implemented simultaneously;

– analyze how to minimize the damage that the measures being implemented may cause;

– determine the consequences that are expected in case of failure to implement the measures.

First of all, occupational risk management measures provided for by state regulatory legal acts on labor protection are determined and implemented.

Then, additional measures are determined and implemented to increase the level of labor safety of employees.

Such measures should be implemented depending on their complexity, financial and resource costs. To implement additional measures, an appropriate program may be developed and approved by the management of the unit.

Based on the results of determining occupational risk management measures, relevant information about these measures is entered into the occupational risk card.

Based on the results of occupational risk management, all hazards that constitute significant occupational risks must be eliminated and the re-assessment of occupational risks from these hazards must constitute "moderate" or "low" occupational risks.

If, as a result of occupational risk management, the identified hazard continues to pose a significant occupational risk, it is not permitted to carry out work or work at workplaces that have such sources of danger.

After conducting an initial assessment of occupational risks at the enterprise, it is necessary to continuously monitor them in order to:

– update data on identified hazards and the magnitude of occupational risks (R) from them;

– verify the effectiveness of measures taken to manage existing occupational risks and, if necessary, revise these measures;

– identify new hazards.

Monitoring of hazards and risks from them should be carried out by conducting:

– reassessment of occupational risks in the event of changes in: technological processes; equipment (equipment, tools) used during the performance of work; materials used; requirements of regulatory legal acts on labor protection, etc. Re-assessment of occupational risks is carried out before the start of work;

– inspections of the state of labor protection at workplaces or during the performance of certain works;

– analysis of the causes of industrial injuries in the unit;

– assessment of occupational risks upon the employee's request regarding the presence of a danger to his life or health during the performance of work or at the workplace;

– extraordinary assessment of occupational risks on the initiative of: management or an employee of the unit, a person who conducts an inspection of the state of labor protection in the unit.

Based on the monitoring results, if necessary, the previously defined occupational risk management measures are adjusted, and the relevant information in the Occupational Risk Card and the Occupational Risk Register is updated.

Given the dynamic development of technologies and the increasing requirements for the efficiency of management decisions, there is a need to implement digital approaches to risk management that ensure their continuous monitoring and adaptation. Current trends in the development of the transport industry indicate the need to implement intelligent risk monitoring systems. It is advisable to use digital tools that provide operational collection, analysis and visualization of data on workplace hazards.

In particular, the use of Internet of Things (IoT), artificial intelligence (AI) and machine learning (ML) technologies allows you to detect potential deviations in real time, predict the occurrence of emergency situations and generate automated signals to management services. The implementation of an integrated digital platform for occupational safety management (IDP-OP) allows you to combine data from various sources: environmental sensors, transport control systems, medical indicators of employees, etc. This increases the accuracy of risk assessment, ensures the preventive nature of management decisions and forms a safety culture at the enterprise. The developed model of the integrated occupational risk management system (MISUR) is designed to combine traditional principles of occupational safety with the capabilities of modern digital technologies. It reflects the relationship between risk assessment, management and monitoring in the continuous improvement cycle (PDCA) [14].

The planning stage (Plan) involves identifying hazards, determining the probability of their occurrence, predicting consequences, and developing risk management strategies. The implementation (Do) stage involves implementing planned safety measures, training personnel, technical modernization, and digital monitoring. The verification stage (Check) involves assessing the effectiveness of the measures taken, analyzing the results, identifying deviations and residual risks. The final corrective action stage (Act) is aimed at updating the occupational health and safety policy, adjusting safety programs, and improving risk management procedures [15].

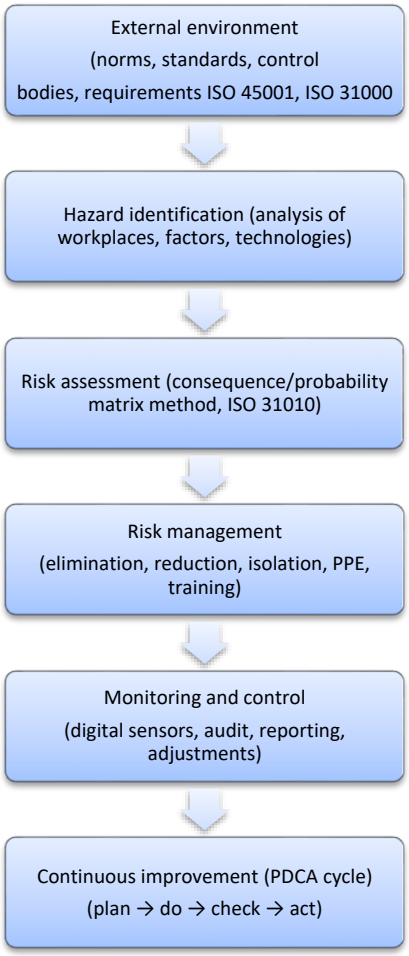

Figure 2 – Model of the integrated occupational risk management system (MISUR)
Figure 2 – Модель інтегрованої системи управління професійними ризиками (MISUR)

A feature of the MISUR model is its integration with digital technologies, which provide continuous feedback between all stages of the PDCA cycle (Figure 2). This allows you to create an adaptive system that can quickly respond to changes in the production environment, maintain a high level of safety culture and make management decisions based on objective data. Thus, the MISUR model forms a holistic and flexible risk management mechanism that meets modern trends in the development of the transport industry and the digital economy.

Therefore, the introduction of digital technologies into the occupational health and safety management system opens up new opportunities for forecasting, controlling and preventing occupational hazards. The use of the integrated MISUR model ensures the consistency and continuity of risk management processes, contributes to the formation of a proactive safety culture and increases the competitiveness of transport enterprises in modern conditions of the development of the digital economy.

Conclusions. The study proves that effective occupational risk management is a key factor in ensuring occupational safety at transport enterprises. The proposed integrated approach to risk assessment and reduction, built on the principles of international standards ISO 31000 and ISO 45001, allows for a systematic combination of the processes of hazard identification, their quantitative assessment and the implementation of preventive measures.

The use of the "consequence/probability matrix" methods provides the ability to clearly determine the level of significance of each risk, which is the basis for making informed management decisions. The use of modern digital technologies - such as artificial intelligence, data analytics, IoT-based monitoring systems - opens up new opportunities for hazard prediction, optimization of control and increasing the accuracy of risk assessment in real time.

The developed model of the integrated occupational risk management system (MISUR) demonstrates the relationship between risk assessment, management and monitoring in the continuous improvement cycle (PDCA). Its practical implementation will contribute to improving safety culture, reducing occupational injuries, forming a proactive approach to occupational safety, and ensuring sustainable development of transport enterprises in Ukraine.

Thus, the proposed approach is not only theoretically sound, but also has significant potential for practical application in occupational safety management systems in the transport industry in the context of digital transformation.

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ІНТЕГРОВАНИЙ ПІДХІД ДО МОДЕЛЮВАННЯ ТА ЗМЕНШЕННЯ РИЗИКІВ У СИСТЕМІ УПРАВЛІННЯ ОХОРОНОЮ ПРАЦІ ПІДПРИЄМСТВ ТРАНСПОРТНОЇ ГАЛУЗІ

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Анотація У статті проаналізовано сучасні підходи до управління охороною праці на транспортних підприємствах України з урахуванням останніх технологічних викликів, ризиків та міжнародних стандартів. Дослідження обґрунтовує необхідність систематичної ідентифікації та оцінки професійних ризиків, що виникають у виробничих процесах транспортних підприємств, а також розробки превентивних та коригувальних заходів на основі принципів стандартів ISO 31000 та ISO 45001.

Особливий акцент робиться на впровадженні цифрових інструментів та інтелектуальних систем моніторингу, що дозволяють в режимі реального часу виявляти та прогнозувати потенційні небезпеки. У статті пропонується впровадження інтегрованої цифрової платформи управління охороною праці (IDP-OS) та представлено модель інтегрованої системи управління професійними ризиками (MISUR), яка поєднує класичні та цифрові підходи до управління ризиками в рамках циклу постійного вдосконалення PDCA (Plan–Do–Check–Act).

Об'єктом дослідження є міжнародні стандарти та методологічні підходи до систем управління професійними ризиками.

Метою дослідження є аналіз та розробка інтегрованої моделі управління професійною безпекою, орієнтованої на ризики, відповідно до міжнародних стандартів для підвищення культури безпеки та забезпечення сталого розвитку транспортних підприємств.

Методи дослідження – аналітичний, порівняльний, системний.

Результати дослідження можуть бути рекомендовані для впровадження в системах управління охороною праці українських транспортних підприємств з метою поліпшення прогнозування ризиків, зменшення виробничого травматизму та підвищення ефективності діяльності.

Ключові слова: управління, орієнтоване на ризики, охорона праці, транспорт, безпека праці, виробничий процес, модель, методологія, цифрові технології, ідентифікація, оптимізація

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