KAPITEL 9 / *CHAPTER 9* [9]
THE USE OF IMMERSIVE TECHNOLOGIES AS AN INNOVATIVE ELEMENT OF THE SAFETY AND SECURITY SYSTEM FOR PERSONNEL OF MACHINE-BUILDING ENTERPRISES

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Introduction

Modern machine-building enterprises operate in a dynamic and unstable environment, where the technological complexity of production processes is combined with elevated levels of man-made risk. The issue of protecting personnel in emergency situations – caused by both internal accidents and external threats such as explosions, fires, chemical leaks, or military actions – is of particular relevance. Under such circumstances, traditional approaches to safety organization, including briefings, tabletop exercises, and scheduled drills, are insufficient for developing sustainable behavioral skills in high-stress and unforeseen scenarios.

The use of immersive technologies – such as virtual reality (VR), augmented reality (AR), and mixed reality (MR) – offers new prospects for creating effective, adaptive, and realistic training environments. These environments enable employees to practice critical response algorithms without putting their lives or health at risk. Such technologies are already being utilized in the energy, aviation, and oil and gas industries, and they hold strong potential for integration into the machine-building sector, where the consequences of industrial accidents can be catastrophic.

The relevance of the study is due to the need to increase the level of operational readiness of personnel to act in emergency situations, as well as the need for enterprises to introduce innovative security technologies. Immersive technologies are able to provide a comprehensive simulation of the production environment, modeling of emergency events, and adaptation of the training process to the specific conditions of the facility, which significantly increases the effectiveness of safety measures. However, despite the rapid development of immersive technologies in the world, their

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use at Ukrainian machine-building enterprises remains limited and fragmented. The lack of implementation standards, as well as insufficient awareness of management and occupational health and safety professionals, hinders the process of digital transformation of the security system. There is an objective need for a scientifically based approach to integrating immersive technologies into emergency preparedness training, as well as to study their impact on the effectiveness of risk management at machine-building enterprises.

9.1. Possibilities of using immersive technologies to protect personnel

The challenges posed by martial law in Ukraine, the constant threat of missile attacks on industrial facilities, cyber attacks, and the high probability of accidents at critical infrastructure facilities require a rethinking of approaches to education and training [1].

At machine-building enterprises, employees may face situations where every second counts, such as a hazardous substance leak, an explosion threat, or a sudden equipment failure [2]. In such conditions, knowledge acquired formally, without practical consolidation, is not activated in time. Stress can block rational thinking, reduce concentration, and slow down reactions, which in critical conditions can lead to catastrophic consequences for both the employee and the entire production process [3]. Let's formulate the areas of use of immersive technologies for organizing the security of enterprise personnel (Figure 1).

One of the main areas of VR application is the protection of enterprise personnel through interactive education and training. With the help of realistic simulations, employees can undergo practical training in a virtual space that simulates complex or dangerous work situations. A striking example is the ITPS VR Training platform [4], which is used to train employees in the petrochemical and gas production industries. In particular, Shell has successfully used VR training for its employees who operate offshore drilling platforms. In a virtual environment, they can practice actions in case of gas leaks or fires without risking their lives, which is impossible in reality without compromising safety [5].

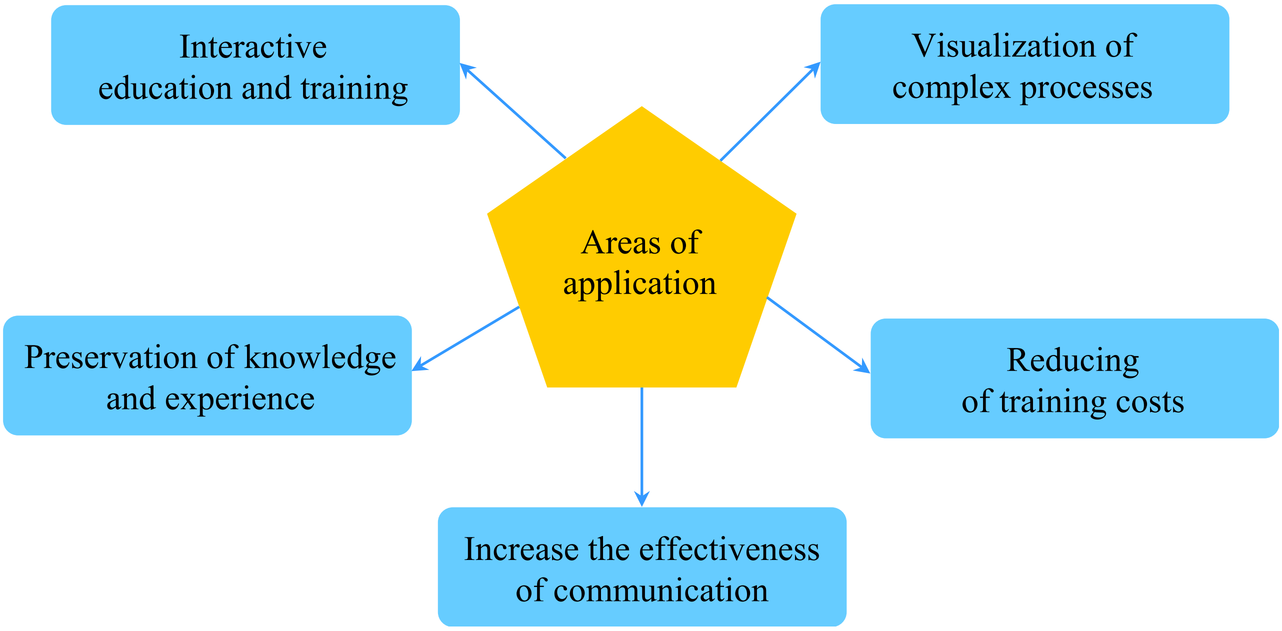

Figure 1 – Directions of using immersive technologies to organize the security of enterprise personnel

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Other leading oil and gas companies, such as British Petroleum, ExxonMobil, Chevron, use virtual reality to train and optimize workflows during operations [6].

Thus, thanks to the ability to create realistic simulations, VR provides employees with a safe training environment, allowing them to practice algorithms for actions in critical or potentially dangerous conditions.

Another advantage of VR is the visualization of complex production processes and the internal structure of technical equipment. This allows the staff to better understand the principles of operation of machines and mechanisms and can study the structure of the equipment, its principles of operation, and typical malfunctions in detail. For example, Siemens uses VR models of its industrial turbines to train maintenance personnel. Employees are able to virtually "disassemble" and "assemble" a complex mechanism without wasting resources on physical training samples and without creating a risk of equipment damage [7].

VR also plays an important role in improving the efficiency of internal communication and teamwork. Thanks to platforms such as Vizible [8] or Engage [9], remote teams can work together in a virtual space to simulate production situations, analyze risks, or hold security meetings. This is especially true for companies that have branches or facilities in different regions, such as those in the mining or oil industries. Boeing uses VR to train engineers who work on the installation of aircraft systems, even when they are in different countries. It reduces the training time by 75% for one person, and thanks to augmented reality (AR) technology, the accuracy is increased by 33% [10].

One of the key tasks of VR in corporate training is to preserve knowledge and transfer experience from experienced professionals to junior employees. By creating virtual instructions or scenarios based on real-world experience, companies minimize the risk of losing critical competencies. For example, Nestlé has implemented a VR program where virtual instructors (avatars of experienced employees) accompany newcomers at every stage of the production process on the production line [11].

Finally, it is important to note that VR reduces training costs and reduces the number of production errors. While the initial investment can be substantial (equipment purchase, content development, staff training), it pays off in reduced accidents, minimized errors, and shorter training times. For example, UPS uses VR to train truck drivers: using simulations, they practice driving scenarios in difficult weather conditions or when transporting dangerous goods, which has significantly reduced the number of traffic accidents among new employees [12].

Thus, the use of VR in personnel training not only increases the level of individual safety of employees but also provides enterprises with a strategic advantage through more effective risk management, better training, and preservation of production potential.

9.2. Practical aspects of VR implementation at an engineering enterprise

Implementing virtual reality at a machine-building enterprise requires comprehensive preparation – not only the purchase of equipment but also the

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transformation of internal processes, personnel structure, and safety culture.

Technical requirements include hardware and software. Hardware includes virtual reality helmets (e.g., HTC Vive, Meta Quest, PICO), controllers, motion sensors, and powerful computers or VR stations capable of handling real-time graphics. Specialized software (e.g., Pixaera, VRTU, and Unity with custom solutions) is required to model training scenarios, manage the learning process, and collect analytics. A stable Internet connection is important if training is conducted in a cloud environment or with access to remote teachers.

Organizational requirements include the creation or adaptation of internal regulations: regulations on VR training, training schedules, instructions for using VR technologies, and an employee access system. It is necessary to appoint responsible persons for conducting VR training, as well as to ensure cooperation between the occupational health and safety departments, IT service, the company's training center, and external content developers.

Staffing requirements include the need for specialists with basic skills in working with VR equipment and software. These can be occupational safety engineers, staff training instructors, or specially trained VR trainers. It is also important to train employees themselves, both in the technical use of VR systems and in safe behavior in the virtual environment. If complex scenarios are used, external VR developers, designers, and mentors should be hired if possible.

The development of an effective VR scenario for the professional training of personnel at an engineering enterprise involves several interrelated stages (Figure 2).

The process begins with a detailed analysis of the production environment, which includes the study of technological processes, hazardous areas, typical emergency situations and the specifics of employees' work. This allows us to formulate training objectives in accordance with the needs of a particular facility.

The next step is to define the learning objectives and competencies that employees should develop after completing VR training. These can be both general emergency skills and highly specialized operations related to specific equipment or production areas.

After that, engineers work with IT specialists to develop the content and logic of the VR scenario. They define the events that will take place in the virtual environment, possible user actions, and algorithms for responding to certain changes in the situation. Particular attention is paid to modeling risk factors and dynamic conditions, such as reduced visibility, noise, obstacles, and the need for quick decision-making. Based on the information collected, the development team creates three-dimensional models of the production environment. They should reflect the real conditions, interior, equipment placement, and evacuation routes as accurately as possible.

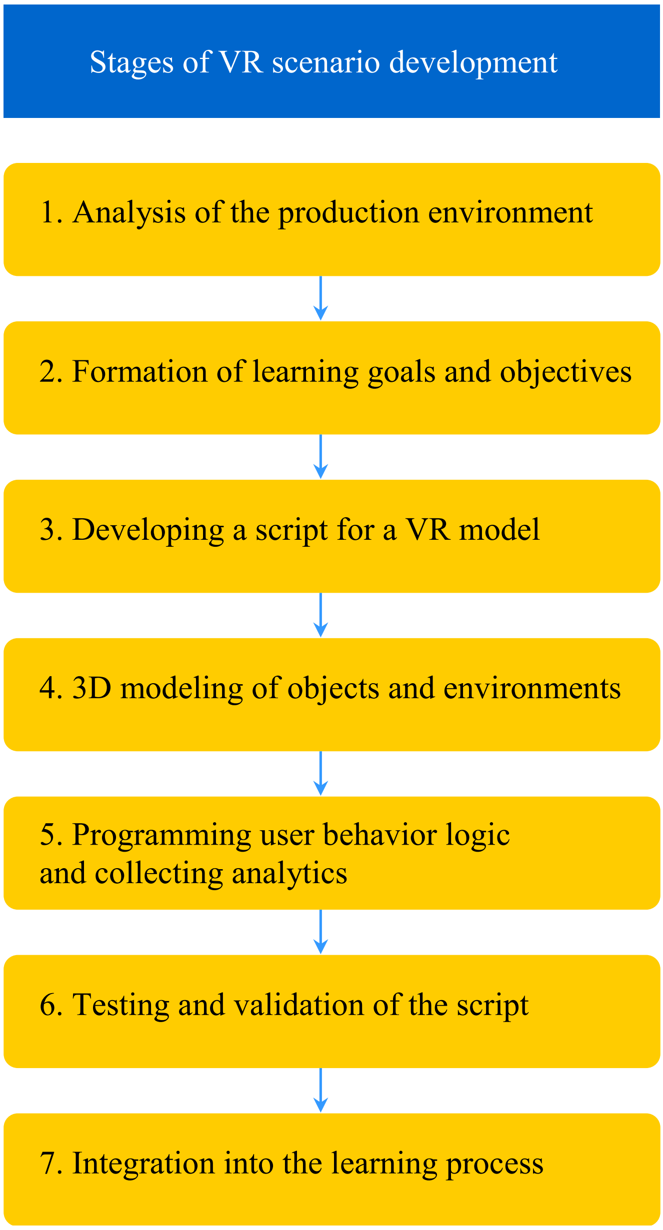

Figure 2 – Algorithm for developing VR scenarios for the specifics of the enterprise

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The logic of user interaction with objects in the VR space is programmed in parallel. An employee in virtual reality should be able to perform actions that correspond to his or her real work – operate mechanisms, apply protective equipment, click on control panels, etc. All user actions are recorded: reaction time, correctness of decisions, and error rate. This data serves as the basis for feedback and further evaluation of learning outcomes.

Once the technical development is complete, the scenario is tested. Representatives of the target group – the employees for whom the training was created – are involved. Based on the feedback, optimization takes place: the interface is improved, the complexity is adjusted, and the tasks are clarified.

The final stage is the implementation of the VR scenario in the training process at the enterprise. Training plans are formed, the frequency of VR training is determined, methods of final evaluation are developed, and documentation confirming the training results is systematized. Thus, VR scenarios are integrated into the company's occupational health and safety system as one of the full-fledged tools for training and monitoring staff knowledge.

The introduction of virtual reality technologies into professional training at machine-building enterprises is inextricably linked to the factor of human perception. Even with modern equipment and methodological solutions, the effectiveness of VR training largely depends on how these innovations are perceived by direct users.

This issue is particularly acute among older workers, for whom digital technologies can generally be a source of discomfort. They are more likely than others to need additional help, explanations, and adaptation of the interface to their cognitive characteristics (e.g., simplified controls, large font, step-by-step instructions, etc.). If such measures are not taken, VR training can cause a feeling of confusion and thus reduce the level of learning. For example, Equinor, a Norwegian oil and gas company, has implemented VR to train its staff to work on offshore platforms. One of the challenges identified during the project was the technophobia of some employees, especially those who had never used either VR helmets or computers before. To reduce tension, the company integrated voiceover instructions into VR modules and adapted graphics to a minimalist, intuitive interface. As a result, even those who initially showed resistance began to use VR for self-training on their own.

In most cases, the main obstacle to VR integration is *psychological inertia*: employees who have long been accustomed to traditional forms of instruction show some resistance to new approaches. It can be manifested in distrust of virtual learning, doubts about its effectiveness, unwillingness to "learn in a new way," and sometimes in fear of losing control of the situation in an unfamiliar digital environment.

In addition, *personal previous experience with digital devices* is an important factor. Employees who have minimal or fragmentary experience with computers, smartphones, or multimedia systems may have difficulty running VR scenarios or navigating the virtual environment. In this case, there is a need for preliminary training in VR technology, which lengthens the overall staff training cycle. Siemens, which uses VR modeling to train engineers, faced the fact that some engineers preferred printed schematics in a pilot project, considering them more "visual" and "controllable." To solve this problem, Siemens introduced a combined format: first, employees were offered traditional instructions, then a VR scenario, and at the end, a final module with a comparative analysis. This gradual adaptation helped to reduce the psychological barrier and increase readiness to use new technologies.

Also, the perception of VR technologies depends on the *user's physiological reaction* to being in a virtual environment. Having a cyber illness, a tendency to dizziness, loss of orientation, or excessive visual load forms a negative association with VR experience and can lead to refusal to participate in training.

Thus, for the effective implementation of virtual technologies at a machine-building enterprise, it is necessary to take into account the individual characteristics of the perception of innovations. We are talking about both cognitive and psychological aspects, as well as social conditions that affect the willingness of employees to engage in the innovative learning process. The effectiveness of VR training is greatly enhanced when the needs and fears of employees are taken into account, support and explanations are provided, and gradual immersion in the new training format is provided.

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Conclusions

The results of the study show that the introduction of immersive technologies, in particular virtual reality, is an effective tool for improving labor safety at machine building enterprises, especially in the context of martial law, technological instability, and increased external threats. The traditional system of staff briefings and training is insufficient to form sustainable responses in emergency situations, while VR allows employees to repeatedly simulate complex scenarios, consolidating effective action algorithms in a safe virtual environment.

The algorithm for creating VR scenarios, taking into account the specifics of the enterprise, provides a structured approach to training: from analyzing the production environment to testing, feedback, and full integration into the occupational health and safety system. At the same time, the technical, organizational, and personnel aspects of VR implementation require careful preparation, coordination between the structural units of the enterprise, and appropriate methodological support.

One of the key challenges is employee acceptance of new technologies. To ensure effective engagement in VR training, it is necessary to take into account digital literacy, age, and psychological characteristics, as well as physiological limitations of users. Resistance to change can be overcome through a flexible approach, a blended learning model, internal support from management, and the creation of a secure information space.

The introduction of VR at Ukrainian machine-building enterprises can become not only a technological breakthrough but also a strategy for long-term strengthening of industrial safety, reducing production risks, and increasing the resilience of critical infrastructure to destabilizing factors.

In the future, VR can play a key role in shaping a new safety culture at industrial enterprises, where each employee not only knows the instructions but practically practices them in realistic conditions.

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