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DEVELOPMENT OF A METHOD FOR ASSESSING THE EFFICIENCY OF TECHNICAL SYSTEMS' COMPUTER DYNAMIC SIMULATORS

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The object of the study is the process of assessing the effectiveness of technical systems' computer dynamic simulators. The subject of the study is methods for assessing the effectiveness of dynamic simulators taking into account the criteria of economic efficiency of training of those who study. The assessment of the effectiveness of technical systems' simulators is associated with the audit of the skills of making correct management decisions in the conditions of a complex information environment.

The advantage of this study is to assess the effectiveness of technical systems' computer dynamic simulators that use artificial intelligence to improve training in the necessary skills in a short time, taking into account the economic component. The essence of the method is to use the proposed criteria to adequately assess the effectiveness of simulator training. The method allows to compare simulators with each other and justify ways of their development and improvement. A feature of the developed method is the proposed procedure for building and studying a simulation model that reproduces the real processes of the functioning of a technical system in a simulator. A simulation model of a real technical system through the use of the artificial intelligence function allows to improve the realism of the simulator and reduce the training time by up to 30 %. This is explained by the fact that the use of simulators with artificial intelligence will allow to more realistically simulate the processes of the functioning of a real technical system. The proposed method allows to substantiate the potential possibilities of using the simulator system in the process of practical training. The results of the study allow to evaluate the simulators to improve the quality of practical training of operators and to substantiate the directions of development and modernization of simulators

Keywords: simulation model, efficiency criteria, training, operator, practical training, technical system

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1. Introduction

The level of professional skill of the service personnel (crew) and the result of the functional purpose of the real technical system directly depend on the quality and realism of the technical systems' simulators and the content of the training, the organization and conduct of the educational process [1, 2]. Under the technical system in the study, vare ious objects are taken as the basis, the training of which requires the involvement of simulators: from a car simulator to a simulator of the control panel of the production process (automated workplace). These circumstances necessitate the unification of training at all levels, starting from the educational institution (training center) and ending with the permanent place of performance of their functional duties.

Regardless of the level of training, the main requirements for service personnel (operators) are the following:

– developing sustainable skills for making correct management decisions in a complex information environment (for example, a navigator when controlling air traffic in a separate airspace);

– developing skills and abilities in the use of standard technical complexes and systems;

– acquiring the skills to make the right decision in regular and irregular situations that arise during the operation of technical systems.

Developing the skills of making correct management decisions in a complex information environment is a more important task of simulator training [3]. An integral part of such training are tasks, the content of which combines the functional capabilities of the simulator and the methodology used by the class leader (instructor) to solve the educational tasks set in the program [4].

Therefore, complex (computer dynamic) simulators for training operators must be effective not only from the functional side, but also from the methodological and economic point of view. That is, the simulators must ensure the achievement of training indicators according to the following criteria:

– training tasks coverage completeness, focused on each operator;

– adequacy of the curriculum to the purpose and content of practical training for work on the technical system;

– expenses for simulators providing practical training.

Thus, the current task is to develop a method for assessing the effectiveness of technical systems' computer dynamic simulators used in the training of technical systems operators.

2. Literature review and problem statement.

The paper [5] considers the integration of Hardware in the Loop (HiL) into dynamic simulators for steering testing, which is an important step in the development of effective technical systems' simulators. It describes the transfer of the capabilities of a static test bench to a dynamic simulator, which can increase the accuracy of the simulation of physical processes and control. However, it does not detail how exactly the synchronization between physical and virtual components is implemented, what algorithms are used for feedback, and how real-time and data transmission delay issues are addressed. There is also a lack of clear metrics for simulation efficiency and comparison with other modeling methods.

The paper [6] analyzes the possibility of using the SIMBIONIX GI Mentor II endoscopic computer simulator to assess the professional skills of endoscopists, which is important for improving the quality of medical procedures. The study demonstrated a correlation between the rate of successful cecal intubation (CIR) in real conditions and the performance of doctors on the simulator, in particular in the Endobubble test, which assesses manual dexterity. However, it is not explained to what extent the results are statistically significant, and it does not mention possible limitations, such as the influence of the learning effect or other factors that may affect the performance of doctors. In addition, there is no information on whether the simulator can effectively assess other key skills, in addition to motor skills.

The work [7] is devoted to the development of a modern web-based MIPS simulator that overcomes the limitations of traditional tools such as MARS by adding data path visualization, step-by-step execution, and integration into a web browser. This makes the simulator more accessible and convenient for students, which can significantly improve the learning process. However, no information is provided about the comparison with existing tools in terms of learning efficiency metrics. It is also not mentioned how much the simulator covers all aspects of the MIPS architecture and whether it supports realistic program execution scenarios. There is no data on the performance of the simulator in the browser and possible limitations in functionality. Overall, the article offers a promising approach, but requires a more detailed analysis of the impact of the developed tool on the quality of education.

The work [8] discusses the use of dynamic systems simulators to model and analyze CDMA performance, which is an important aspect of evaluating modern wireless technologies. It emphasizes the advantages of this approach for studying complex algorithms and the relationship between key performance parameters. However, the paper does not specify which simulator is used, which specific metrics are analyzed, and whether a comparison with other modeling methods has been made. There is no information on the accuracy and computational efficiency of the proposed approach. It also does not state whether the study takes into account the influence of real-world factors such as noise, interference, and network load changes.

The authors in [9] propose a Bayesian perspective for active learning that uses Gaussian process regression to estimate the response probability distribution of expensive computer simulators. This approach allows for more accurate accounting for sampling errors, incorporating prior knowledge about the simulators, and reducing numerical uncertainty to a given level. However, the paper does not state how effective this method is compared to other existing approaches to estimating probability distributions, and whether there are specific limitations when applying it to different types of simulators. There are also no details about the complexity of numerical calculations when using the proposed method, which is important for practical application in real-world problems. In addition, it is not stated whether possible variations in the data that could affect the accuracy of the estimate were taken into account.

The study [10] provides an overview of open source dynamic simulators that support the inverting grid forming (GFM) technique and assesses their potential for machine learning applications. It highlights the advantages of such simulators, such as their freeness and customizability, which make them ideal for research and testing new methods. However, the paper does not provide a detailed comparison of the performance of different simulators in real-world scenarios or their ability to integrate with other popular machine learning tools. It also does not address whether there are any modeling accuracy or computational complexity issues that may arise when using open source. Furthermore, it does not address the optimization of these simulators for large-scale or real-world industrial applications.

A study [11] analyzed the effectiveness of using a wave machine and a computer simulator in teaching students the basic concepts of waves. The results of the study showed that both tools had a positive impact on student performance, achieving "outstanding" results with no significant differences between the methods. However, the study indicates that there is no direct relationship between students' interest in these methods and their performance. This suggests that while the use of hands-on and digital approaches can increase student interest and engagement, the changes in performance are not always significant. It is important to note that although interest in these tools was high, learning performance remained stable. This approach demonstrates the potential for the combined use of physical and digital teaching methods in the educational process, which allows making classes more engaging without significantly affecting the final results.

The work [12] focuses on the application of the SOLIDWORKS Motion computer-aided design system to solve problems of kinematics and dynamics of technical systems, such as mechanisms and machines. In particular, the use of this system for numerical experiments, verification of the operability of mechanisms and optimization of their characteristics is considered. The results presented in the article demonstrate how SOLIDWORKS Motion can be useful not only in the educational process, but also in the real design of mechanisms, such as clutches, cam mechanisms and gears. The authors emphasize that the use of such systems allows to significantly simplify the design process, reduce time and perform multi-parameter optimization, which is important for increasing the efficiency of the development of technical systems. In addition, this technology provides an opportunity to integrate students' theoretical knowledge with practical activities, which makes learning more interactive and interesting. However, it is worth noting that despite the advantages of using computer simulators, additional checks and verification of models are required to achieve high accuracy of results, since not all parameters can be accurately reflected in numerical calculations.

The study [13] highlights the significant progress in the field of computer and web-based simulations, which arose due to technological innovations and the need for effective training of qualified specialists. It emphasizes how simulators that reproduce limited aspects of physical environments achieve high fidelity, which allows for significantly improved transfer of procedural knowledge compared to traditional textbooks and methods. Web-based simulators, in turn, provide easier access to training materials, as well as the possibility of real-time updates and multi-user scenarios, which opens up new opportunities for communication and collective learning. The authors point out the importance of simulations for improving training processes and identifying performance gaps that can be used for targeted changes in training programs. Given these advantages, computer and web-based simulators with high fidelity and reliability are becoming important tools not only for training personnel, but also for evaluating the effectiveness of training processes.

The study [14] proposes a new dynamic tactile synthetic fabric for surgical simulators that combines sensors and actuators to achieve realistic feedback in real time. This fabric uses hydraulic principles and sensor layers to measure pressure and deformation, which allows for effective imitation of physiological responses. The use of such materials in modeling artificial organs, such as the brain or heart, significantly improves the realism of simulators. The main drawback is the limitation in scaling the technology, since the accuracy of simulations may decrease on large objects or in complex physiological scenarios. Further verification of this technology in practice is also necessary to confirm its effectiveness in various clinical situations.

The work [15] proposes an effective framework for developing 6G simulators, in particular, addressing the computational complexity issue. A performance improvement of up to 100 times is a significant achievement, however, this architecture can be difficult to integrate with existing systems. It also requires significant computational resources, which may be a limitation for some users. In addition, although the new framework effectively improves the simulation of 6G networks, the results may vary depending on the specific testing conditions. This means that full implementation in practice may encounter technical difficulties, especially when using non-standard network configurations.

The study [16] describes the integration of artificial intelligence (AI) with dynamic power system simulators, which allows to significantly increase the accuracy and efficiency of power system modeling. The proposed approach uses a high-performance simulator with neural network support and API to provide interaction between power system modeling and AI. The developed prototype was successfully tested using several scenarios, confirming its validity and flexibility. However, there are certain limitations, in particular, the need for significant computing resources to process large amounts of data and possible difficulties in adapting to new, unpredictable conditions. In addition, it is necessary to consider the impact of inaccuracies in AI models on the long-term stability of power systems.

The work [17] describes the development of an accessible and user-friendly dynamic reactor simulator, created in Microsoft Excel (USA), which has the potential to be used in educational institutions where there is limited access to paid software licenses. This solution allows students and teachers to effectively simulate dynamic processes without the need for expensive software products such as Matlab (USA). One of the main advantages is the use of the already widely available Excel, which facilitates the implementation of simulations in the educational process and makes it more accessible to budgetary institutions. However, although the use of Excel allows to reduce costs, this approach has certain limitations, in particular in the scale and complexity of simulations, compared to more specialized programs. In addition, the accuracy of the simulation may be limited due to the capabilities of Excel compared to professional simulators that can process more complex mathematical models and large amounts of data. It should also be noted that this simulator may not support all the functions necessary for realistic simulations in industrial conditions, which limits its application outside educational institutions.

The study [18] examines the importance of using marine simulators for the development of autonomous vessels, in particular marine autonomous surface ships (MASS). It emphasizes that mathematical models of ship maneuvering are critical for such simulators and help to evaluate and train autonomous navigation algorithms. The authors discuss the choice of a dynamic ship hull model that should be adapted for future MASS, as well as the functional requirements for simulators, which is important for ensuring the effectiveness of such systems in real-world conditions. Special attention is paid to the selection of appropriate models, as this is an important aspect for the accuracy of simulations. The shortcomings of the article are insufficient coverage of the potential challenges that developers face when integrating maneuvering models into real-world systems, as well as the limited number of practical examples of the use of simulators for MASS. In addition, the issue of scaling such models and their adaptation to different types of autonomous vessels is not fully considered, which may limit the applicability of the proposed approaches to a wider range of tasks.

Thus, the absence of training equipment (simulators) does not provide high-quality training, and also does not allow to work out the obtained training results in practice. The development of timely changes and improvements to training equipment should be based on reasonable criteria for assessing their effectiveness. Therefore, the development of a method for assessing the effectiveness of computer dynamic training equipment of technical systems is advisable. In addition, in order to improve the quality of operator training, training systems using artificial intelligence systems should be considered.

3. The aim and objectives of the study

The aim of the study is to develop a method for assessing the effectiveness of technical systems' computer dynamic simulators, which will make it possible to significantly reduce the time for training students. This will make it possible to conduct an adequate assessment of the effectiveness of simulator training, compare simulators with each other and justify ways of their development and improvement.

To achieve the aim of the study, it is necessary to solve the following tasks:

– to substantiate the scheme of reproducing the procedure for operating technical systems simulators using artificial intelligence;

– to substantiate the effectiveness criteria and the method of evaluating the effectiveness of technical systems' computer dynamic simulators;

– to verify the proposed criteria and method for evaluating the effectiveness of technical systems' computer dynamic simulators.

4. Materials and methods

The object of the study is the process of evaluating technical systems' computer dynamic simulators. The subject of the study is methods for evaluating the effectiveness of dynamic simulators, taking into account the criteria of economic efficiency of training students.

The hypothesis of the study is that technical systems' computer dynamic simulators, in particular using an artificial element of their evaluation, will make it possible to significantly reduce the time for training students.

To evaluate the effectiveness of the simulator complex, the following questions were identified:

– what tasks and exercises can be practiced on simulators;

– which training competencies, from those defined in the qualification characteristics, are provided by the simulator;

– what functions of the automated workplace equipment (AWE) are implemented in the simulator;

– what methods of evaluating operator actions are implemented in the simulator.

In the field of simulator equipment layout, various methods have been repeatedly proposed for determining the effectiveness of the use of complex simulators both in the industrial sector and in individual sectors of the national economy [2, 10, 16]. At the same time, effectiveness assessments based on the analysis of one or several individual characteristics do not take into account the methodological and organizational features of the use of simulators in the process of practical training of operators of complex technical systems, that is, their didactic capabilities.

The assessment of the economic efficiency of training using simulators was mainly carried out on the basis of comparing the hourly cost of operating the simulator and the real technical system. In addition, the training efficiency coefficient was also considered, which shows how many hours of use of the real technical system for training purposes corresponds to one hour of training on the simulator [1].

Known estimates of the effectiveness of simulators are based either only on economic indicators that do not take into account the effectiveness of using simulators in the process of practical training of operators, or use separate indicators for comparison.

The didactic characteristics of simulators, which determine the effectiveness of the simulator complex as a technical means of training, are especially incompletely studied.

The effectiveness of the complex of simulators used is one of the main indicators that determine the effectiveness of both the training itself and the final assessment of the skills and abilities acquired by operators.

In order to determine the effectiveness of using simulators in the process of practical training of operators, it is necessary to take into account the requirements of qualification characteristics and factors that determine the suitability of the simulator for specific tasks assigned to the operating personnel.

Simulator training is the main method for creating a foundation of both skills and knowledge, thanks to the combination of a high level of proximity of the learning process to real actions.

For high efficiency of educational and practical training on the simulator, it is necessary to fulfill the following indicators:

– effectiveness of the training methodology;

– quality and adequacy of training programs;

– professional and sufficient practical experience of the leader (instructor);

– effectiveness of the simulator used;

– high level of organization of the combat and technical training process.

The main criteria by which it is proposed to evaluate simulators of modern technical systems.

1. Training effectiveness:

– the degree of fulfillment of tasks and requirements of practical training programs, courses on management of workstations, production process, car driving courses: individual simulators; complex simulators for crews; simulators for collective use (for example, the next shift of a power plant, management of route flows of railway transport, etc.);

– ensuring the ability to determine the initial and current level of: skills of those specialists being trained (for individual simulators); coordination of crews and shifts (for complex simulators);

– ensuring the possibility of professional selection (testing) of specialists based on simulators.

2. Adequacy:

– completeness of reproduction of workplace equipment and technical systems implemented by the simulator;

– correspondence of the sensory-motor field of the simulator's workplaces to the workplaces of technical systems;

– adequacy of the simulation model of technical systems;

– the ability to simulate emergency and non-emergency modes of operation of technical systems;

– completeness of coverage and feasibility of the process of functioning of technical systems;

– the degree to which training and education conditions correspond to real conditions. This indicator includes:

a) completeness of imitation of the phono target environment;

b) compliance of the type and size of the terrain (airspace) area being modeled with the requirements of practical training;

c) compliance of the microclimatic, vibration and noise characteristics of the workplace in the simulator with the real workplace of technical systems;

– the ability to create learning and training conditions across the full range of predicted operating conditions, covering:

a) the scale and nature of the actions of a real technical system;

b) interference in the optical and radio wave range, possible mechanical interference;

c) time of day and season;

d) atmospheric phenomena (fog of varying intensity, rain, snow, wind);

e) air temperature and atmospheric pressure;

f) type of terrain (plain, mountainous, desert);

– the possibility of receiving negative feedback on mistakes made when practicing exercises on the simulator;

– quality of visualization of the phono-target environment in the field of view of the simulator's optical and optoelectronic devices:

a) informational and psychophysical similarity of the phono-target environment, which is reflected in the field of view of the simulators of optical and optoelectronic observation devices of the simulator and the real technical system;

b) dependence of the angular dimensions of objects that simulate the activity of real systems on the distance to them;

c) dimensions, shape, coloring and movement parameters of technical systems;

d) the degree of detail of the near and far zones of a terrain area with vegetation and local objects and artificial structures;

e) taking into account machine body vibrations (MBV) during the operation of a real technical system or its movement;

– use of digital terrain maps in complex and individual simulators;

– reproduction of characteristic audio and visual effects of the functioning of technical systems during their operation and movement.

3. Didactic abilities:

– management of the parameters of the training and information model of the simulator during classes and training in accordance with the goals and objectives of practical training;

– objective control of the actions of those who are learning and automated evaluation of the results of completing educational tasks and exercises;

– degree of automation of the training process (non-automated, automated with rigid or flexible training programming);

– documenting the results of completing training tasks (exercises) during any training period;

– completeness of the simulator's training task library.

4. Reliability:

– service life;

– mean time to failure;

– the average resource of the simulator;

– duration of continuous operation.

5. Standardization and unification:

– software and technical compatibility of technical systems' simulators of the same type;

– the ability to operate simulators of various purposes, configurations and compositions, located in different locations, in network mode;

– open architecture of software and hardware complexes of simulators.

6. Economic and operational parameters:

– cost of the simulator (single and serial model);

– cost of operating the simulator (taking into account energy consumption, maintenance, repairs and the number of specialists who service it);

– possibility of operation in difficult climatic conditions;

– required space for accommodation. Requirements for the classroom (premises);

– ease of maintenance;

– duration of training for the simulator before conducting classes and trainings.

Thus, the main reason for evaluating the effectiveness of technical systems' computer dynamic simulators is to determine the main indicators that determine the skills and abilities acquired by operators.

Therefore, it can be only stated the optimal degree of decentralization, the optimal distribution of decision-making functions between the central body and the system's links. Such a system of views on the causes of the emergence of a hierarchical structure in management systems opens up the possibility of widespread use of operational analysis methods for research.

In this study, the results of simulation modeling of the characteristics of the proposed simulator and real complex dynamic simulators were used to assess the effectiveness of technical systems' computer dynamic simulators. When developing a method for assessing the effectiveness of computer dynamic simulators, the following were subject to investigation:

a) hardware:

– complex dynamic simulators for studying controls and rules for driving automobiles. Such simulators include a basic car cabin, an information unit, and dynamic tools. The car cabin contains real-life controls that are connected to the information unit to simulate the driving process. The information unit consists of a system unit (a stationary computer or several computers, depending on the characteristics of the simulator), several monitors (for visualizing the road situation), peripherals (printer, video camera, speakers, etc.). Dynamic tools include a dynamic platform with servo drives to simulate real driving on different sections of the road flow;

– computer (laptop) for implementing the simulation model of the proposed computer dynamic simulator of the technical system;

b) software:

– specialized software for complex dynamic simulators of automotive technology;

– a simulation model has been developed that simulates the process of acquiring knowledge, skills and abilities in driving vehicles. A feature of this model is the automatic adjustment of the complexity of the tasks depending on the actions of the learner.

The initial data for the research are:

– realism of the learning process (correspondence of the simulation (mathematical model and its computer implementation) model to a real sample of automotive equipment. Realism depends on the sequence of actions of the learner, including the number of elements of the control elements (for example, a steering wheel, a gearshift, brake pedals and a speed dial) to simulate the functioning of a real car. It is calculated relative to the total number of such elements of the control algorithm in a real sample of automotive equipment. In this case, the presence of a dynamic platform is taken into account, which significantly enhances the learning process;

– compliance with the requirements of training guidance documents. Depends on the simulator's ability to complete the full training cycle according to the specified program;

– correspondence of the number of elements of the simulator's control elements and the sample of automotive equipment. Calculated relative to the total number of such elements in the real sample of automotive equipment;

– assessment indicators for practicing the exercise, which take into account positive and negative aspects of learning. Calculated relative to the assessment indicators set for passing the driving test.

5. Results of the development of a method for assessing the effectiveness of technical systems` computer dynamic simulators

5. 1. Justification of the scheme for reproducing the procedure for operating technical systems' simulators using artificial intelligence

The simulator (simulator complex) is a software and hardware complex and consists of a simulation device, a supervisor's workplace, trainees' workplaces, and training control equipment; the structure of the complex is shown in Fig. 1 [1, 2, 19].

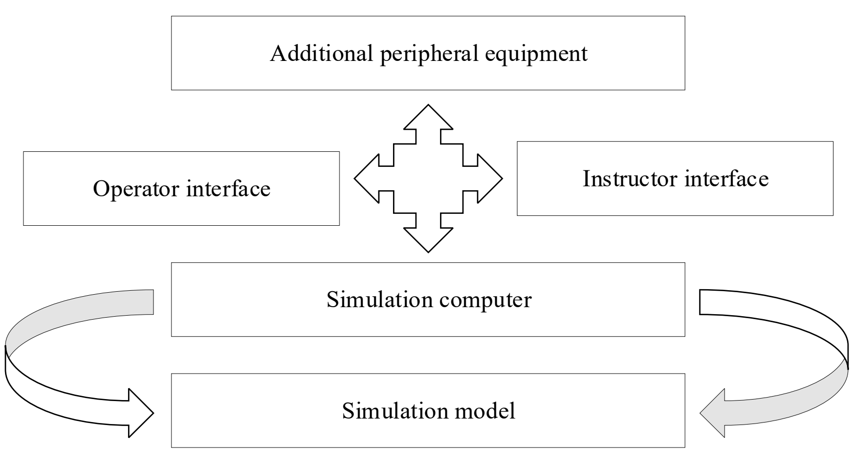

Fig. 1. Diagram of the reproduction of the procedure for operating technical systems simulators

The simulation computer is connected to the operator interface through an input-output system. It provides simulation of training task conditions in real time, the ability to change the complexity of training tasks during training, the ability to dose training tasks, simulation of emergency situations and typical malfunctions, etc.

The operator interface allows to manipulate the controls in a way that is as close as possible to or identical to the actual process being used.

The instructor interface allows to control the operation of the simulator, choose the form and content of the training, the initial state of the simulated process, enter deviations of the simulated process or its components, or change external factors.

The simulation model realistically reflects the interaction of components and systems of the simulated process, similar to the information model in the "human-technology-environment" system.

The simulation system consists of three main components: a model that simulates the phenomenon under study, external and internal support systems.

Therefore, a simulation model is a computational procedure that formally describes the object under study and simulates its behavior; in its form, the model is logical-mathematical (algorithmic).

Simulation models are classified as: static and dynamic; deterministic and stochastic; discrete and continuous.

Additional peripheral equipment includes printers, alarm panels, and any other equipment needed to enhance the realism of the simulated environment or document the training process.

Let`s consider the procedure for constructing and studying a simulation model (SM), which consists of the following: system definition; model formulation (abstraction); data preparation, which involves the following actions:

– model translation – SM description in the appropriate programming language;

– assessment of the adequacy of the transition from the conceptual model to SM;

– strategic planning – planning an experiment that should provide the necessary information;

– tactical planning – determining how to conduct each series of tests as provided for in the experimental plan;

– experimentation – the process of performing simulations to obtain desired data and analyze sensitivity;

– interpretation – drawing conclusions from data obtained through simulation;

– implementation – practical use of the model and (or) modeling results.

Special attention is paid to the stages of planning experiments on the model, because computer simulation can be interpreted as an experiment, due to the fact that the analysis and search for rational solutions are carried out using various methods of experimental planning on the computer.

The nature of the training process is simultaneously influenced by a set of factors, which, according to their characteristics and functional loads, are divided into: technological; dynamic; constructive of real technical systems.

A simulation model of a real technical system when implementing the function of artificial intelligence allows to improve the quality of the simulator. Such an SM with artificial intelligence should contain a block of the "training" procedure. Such procedures allow to respond to the behavior of those who are learning when working out the simulator's algorithm. If necessary, artificial intelligence either adds complexity to working with the simulator or makes the training algorithm simpler. This depends on the level of preparedness of those who are learning. Thus, the use of artificial intelligence in simulators will allow to correct the main drawback of training – the possibility of studying the training algorithm on the simulator. At the same time, the use of simulators with artificial intelligence will allow for a more realistic simulation of the processes of functioning of a real technical system.

5. 2. Substantiation of criteria and development of a method for assessing the effectiveness of technical systems' computer dynamic simulators

The following criteria for assessing the adequacy of a simulator for training technical systems operators are proposed. Adequacy is determined by four factors:

1. Completeness of solved tasks (K_1). The completeness of tasks is the ratio of the number of tasks provided by the simulator to the total number of tasks of the practical training course:

$$K_1 = \frac{K_{p1}}{K_{man1}}, \quad (1)$$

where K_{p1} – the number of tasks that the simulator allows to implement; K_{man1} – the number of tasks that the operator must complete out of the total number of tasks in the practical training course.

If the simulator allows to complete all tasks in their completeness, then K_1=1. The second option – the simulator provides solutions to only part of the tasks specified by the program (it is calculated how many tasks out of the required ones the simulator allows to solve), which is reflected by the equality $0 \leq K_1 \leq 1$. The third possible option is that the simulator does not provide solutions to any of the tasks of the practical training course, K_1=0.

2. Simulator configuration (K_2). Compliance of the simulator configuration with the simulator training tasks. The configuration is defined as a set of software and hardware that provide solutions to a certain list of tasks. Regarding simulators for personnel training, this parameter determines the possibility of teaching the methodology and practice of unit management during the solution of practical training tasks.

Thus, the configuration factor determines the ability of the simulator to create an integrated information environment for practicing actions in real time:

$$K_2 = \frac{K_{p2}}{K_{man2}}, \quad (2)$$

where K_{p2} – the number of configuration elements of the ACS object's workstation that the simulator allows to implement (remote equipment, information model, communication, display means, etc.); K_{man2} – the number of configuration elements of the workstation of a real ACS object.

If K_2=0, then the simulator configuration does not meet the requirements, in case $0<K_2<1$, then the configuration of the simulator allows for the practice of tasks related to the acquisition of skills and abilities.

3. Degree of compliance with the requirements of the qualification specification (K_3). This factor characterizes the quantitative extent to which the requirements for instilling skills, abilities and knowledge in the simulator have been met:

$$K_3 = \frac{K_{p3}}{K_{man3}}, \quad (3)$$

where K_{p3} – the number of competencies specified in the qualification characteristics that the simulator allows to implement; K_{man3} – the number of all competencies specified in the qualification characteristics.

When evaluating the factor "Degree of meeting the requirements of the qualification characteristic", it should be taken into account that the higher the result of the final assessment after training, the higher the effectiveness of the simulator.

Then: K_3=1 – the simulator fully ensures the level of competence of those who are training; K_3=0 – the simulator does not ensure the level of competence of those who are training; $0<K_3<1$ – the simulator partially ensures the level of competence of those who are learning.

4. Quality of evaluation of actions (decisions made) by the operator (K_4). When assessing this factor, the requirements of the governing documents must be taken into account:

– the simulator should provide the ability to verify the level of training achieved by operators – maintenance personnel of real technical systems;

– the simulator should have established and clearly defined assessment criteria to ensure reliability and consistency of assessment; The simulator should enable trainees to demonstrate their ability to perform tasks safely and effectively;

– the simulator is capable of meeting the specific purpose of assessment and training:

$$K_4 = \frac{K_{p4}}{K_{man4}}, \quad (4)$$

where K_{p4} – the number of criteria for evaluating operator actions (task completion time, action algorithm, correctness of operations, etc.) provided by the simulator; K_{man4} – the number of criteria for evaluating operator actions given in the practical training course.

Accordingly, if the simulator is equipped with automatic or automated means of evaluating the operator's actions, using clear criteria and evaluation methodology, then K_4=1. If the simulator does not allow for the evaluation of the operator's actions, then K_4=0. If the simulator is not equipped with automatic or automated means of evaluating the operator's actions, but allows for the assessment of the knowledge, skills and abilities of the trainee, in the event that the instructor applies the assessment criteria and methodology, then $0<K_4<1$.

To provide an assessment of the effectiveness of the simulator, it is necessary to combine partial factors (1)–(4) into an additive indicator of the effectiveness of the simulator.

As an indicator of the effectiveness of the simulator, it is possible to define the functionality Q, which depends on partial factors:

$$Q = \prod_{i=1}^{M} Q_i, \quad Q_i = W_i \times K_i, \quad i = \overline{1, \ldots M}, \quad (5)$$

where M – the number of factors of the indicator of adequacy of the qualification characteristic (in this case M=4); W_i – weighting factors that take into account the importance of individual factors in the overall assessment of effectiveness.

The weighting coefficients in expression (5) take values from zero (the parameter is insignificant, it can be neglected) to one (a very important parameter), the choice of their values depends on the purpose of the system.

Thus, in order to determine the evaluation of the simulator's effectiveness, it is necessary to perform an ordering of the parameters $K_1...K_4$ according to their rank (significance).

It should be noted that the four factors of the adequacy indicator of the qualification characteristic of the simulator are not balanced (equivalent). Each of them has a certain weight value that differs from the other. Thus, if the indicator Q (simulator efficiency) is equal to one, or falls into the interval of values 0.8...1.0, then the simulator can be attributed to the highest class of compliance, which means the following:

– the simulator meets the goals and objectives of the training, it is possible to provide training and assessment on all competencies specified in the qualification characteristics of the specialist;

– the simulator has sufficient and necessary functional completeness, implements all important functions of the workstation equipment (WHE) and ensures the performance of the entire required list of training tasks, i.e. has a complete set of databases necessary for performing functional tasks and tasks that form the initial information.

If the Q indicator falls within the range of values 0...0.5, then the simulator can be classified as a lower compliance class, which means the following:

– the simulator does not fully meet the goals and objectives of the training;

– the simulator does not fully provide the required qualification characteristics;

– the simulator does not have sufficient and necessary functional completeness, i.e. it does not provide for the performance of the entire required list of training tasks, while the set of databases of information necessary for the performance of functions and tasks is missing or not updated.

Thus, the developed method for assessing the effectiveness of technical systems' computer dynamic simulators consists of the following:

1. Evaluation of the simulator for adequacy based on four factors according to formulas (1)–(4).

2. Weight coefficients are calculated for each of the proposed factors. Possible values of weight coefficients range from zero (the parameter is insignificant, it can be neglected) to one (a very important parameter) and depend on the purpose of the simulator.

3. Evaluating the effectiveness of the simulator using generalized functionality, formula (5).

4. Based on the obtained value of the generalized functionality, the class of compliance of the simulator with the real sample of the technical system is determined.

The proposed method for assessing the effectiveness of technical systems' computer dynamic simulators allows for comparing both existing simulators and conducting a comparative analysis of promising simulators using new information technologies (for example, artificial intelligence).

5. 3. Verification of the proposed criteria and method of assessing the effectiveness of technical systems' computer dynamic simulators

The assessment of the adequacy of the proposed simulator for training operators according to the considered factors is determined by the relations (1)–(4), and the effectiveness of the proposed simulator according to the functional Q is determined according to the obtained expression (5), which depends on the partial factors K_i, i=1...4.

Calculations were carried out according to relations (1)–(5) taking into account the data in Table 1 [20].

Table 1

Level of simulation of real processes by complex dynamic simulators (CDS)

CDS name	Year of release	Imitation level
CDS Kamaz 4310	2007	up to 20 %
CDS Kraz	2009	up to 25 %
CDS Zil 130	2008	up to 20 %
CDS Kamaz 4310	2017	up to 60 %
CDS Kraz	2016	up to 65 %
CDS Zil 130	2016	up to 55 %

For a better understanding of the process of evaluating the effectiveness of the simulator, it is possible to show the procedure for calculating the adequacy criteria using the example of Table 2. Thus, from the data in Table 2 it can be seen that the Kamaz 4310 simulator has the lowest level of realism, and the Kraz simulator (2016 model year) has the highest. Thus, the Kraz simulator (2016) is based on a real-life cabin and has all the controls. This allows the simulator to be used instead of a real model to study the car's controls – as a mechanical simulator. However, approximately a third of these controls are not used in the simulator's information channel (for example, the clutch pedal does not work, all axles are engaged, etc.). Therefore, the realism coefficient is obtained at the level of 0.65 (65 % of the characteristics of the real model are taken into account in the simulator).

When developing the simulation model of the computer dynamic simulator, the main shortcomings of the Kraz simulator (2016) were taken into account, but it also contains some shortcomings of the real model. For example, the peculiarities of starting at low temperatures were not taken into account, the dynamics of movement on semi-flat wheels were not taken into account, etc. According to the correspondence of the characteristics taken into account in the simulation model compared to the real model, the simulation coefficient is 0.84.

This coefficient value corresponds to the proposed criterion for the adequacy of the simulator – the quality of the operator's assessment of actions (decisions made) (K_4).

Table 2 presents the results of calculations of partial factors K_i and efficiency Q for existing simulators and the proposed simulator. For simplicity of calculations, weighting factors are defined that take into account the importance of individual factors in the overall efficiency assessment, are the same for existing and proposed simulators and are equal to 1.

Table 2

Results of calculations of partial factors and efficiency for simulators

Simulator	K_1	K_2	K_3	K_4	Q
Existing	0,75	0,85	0,60	0,65	0,25
Proposed	0,87	0,92	0,81	0,84	0,54

According to the data in Table 2, a diagram of the dependence of factors and the effectiveness of existing and proposed simulators was obtained (Fig. 2).

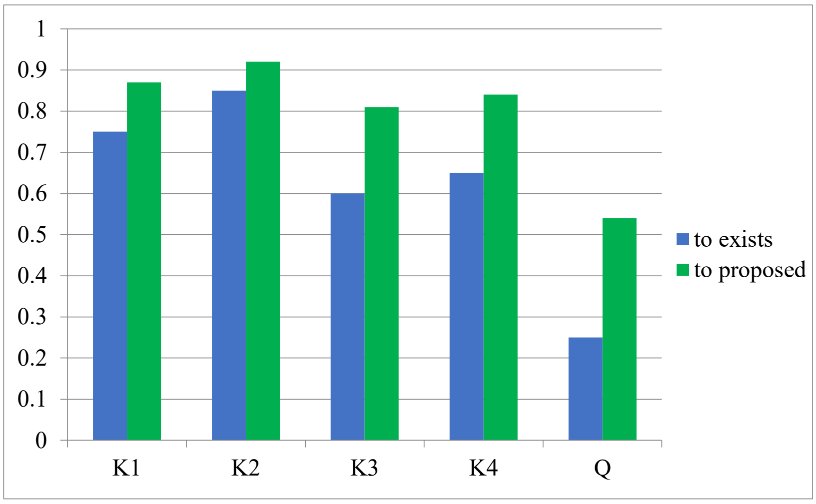

Fig. 2. Dependences of factors and efficiency of existing and proposed simulators

The results of the analysis of the obtained data (Table 2, Fig. 2) show that the use of artificial intelligence functions in technical systems simulators allows to increase the efficiency of using the simulator base in training operators by up to 53 %. The increase in the level of efficiency of using the proposed simulators is carried out by increasing the level of simulation of real processes by the simulators. Therefore, the increase in the overall level of simulation of real processes by the proposed simulators is up to 53 %.

The application of the developed approach allows to determine whether the complex of simulators under consideration meets the requirements for operators to achieve the necessary competencies specified in the requirements of the qualification characteristics, and to assess the effectiveness of the simulator based on the results of training on it.

Assessing the quality of the process of acquiring skills using the proposed training base.

The creation of the latest training complexes and their integration into specialized training and simulation systems in advanced manufacturing countries is based on the detailed design of all elements and a description of the content of the training process as an object of automation. A wide range of specialists are involved in this work, but the leading place is occupied by military methodologists, psychologists, physiologists and physicians.

Analysis of existing training systems created by domestic manufacturers shows that they are focused on the implementation of modern technological and technical solutions to the constructive construction. However, in methodological terms, the technology of their application in the educational and training process remains relatively backward, the level of imitation of real processes does not exceed 70 %.

According to experts, the main factor determining the effectiveness of the use of training complexes is: reducing the time spent on training and developing the relevant professional skills of operators undergoing training in training centers. At the same time, reducing the training time in the process of training using training complexes is characterized by an efficiency coefficient, which should primarily take into account the number of those trained, improving their skills and abilities in mastering the latest technical systems.

The quality of the process of acquiring skills and abilities with the use of simulators and without their use at the first stage (personal with a limited number of actions) can be assessed based on the formula:

$$P(t_0)=e^{-\lambda_0 t_0},\ P(t_1)=e^{-\lambda_1 t_1}, \quad (6)$$

where $P(t_0)$, $P(t_1)$ – probability of relative frequency of random error based on the results of task performance after training with and without the use of the simulator, respectively; λ_0, λ_1 – input error intensity based on the results of completing tasks after conducting classes with and without the use of simulators, respectively; t_0, t_1 – time of acquiring skills and abilities (conducting classes) with and without the use of simulators, respectively.

From dependence (6) the corresponding values of time t_0 and t_1 are determined:

$$t_0=-\frac{P(t_0)}{\lambda_0},\ t_1=-\frac{P(t_1)}{\lambda_1}. \quad (7)$$

The general calculation dependencies for determining the error intensity with and without the use of simulators are as follows:

$$\lambda_0=\frac{1}{n_0},\quad \lambda_1=\frac{1}{n_1}, \quad (8)$$

where n_0, n_1 – the number of errors made based on the results of completing tasks after conducting classes with and without the use of simulators, respectively.

The reduction in the time required to acquire skills (training) during training using training and simulation complexes can be characterized by an efficiency indicator:

$$E_t=\frac{t_0}{t_1}=\frac{P(t_0)}{P(t_1)}\cdot\frac{\lambda_0}{\lambda_1}=\frac{P(t_0)}{P(t_1)}\cdot\frac{n_0}{n_1}. \quad (9)$$

The given dependences (6)–(9) allow to characterize qualitative indicators of training, since it is possible to calculate the necessary time for acquiring skills and training skills. Thus, taking into account the permissible number of errors based on the results of completing tasks after conducting classes both with and without simulators, it is possible to obtain an objective assessment.

According to the research materials, an analysis of the time for performing the algorithm of practical work was obtained, taking into account traditional forms of training and using simulators. To check the adequacy of the results obtained, the time for training the operator of the proposed method was similarly calculated. The results of the comparative analysis of the time for performing the algorithm of practical work of the operator of the production process workstation are shown in Fig. 3.

From Fig. 3 it can be seen that the proposed approach reduces the time for training the operator of the production process using the proposed methods and involving artificial intelligence.

Formally, the learning task can be described as follows. It is possible to assume that the control carried out by a person or a group of people is always subjectively optimal according to some criterion described by the objective function $F(x, u)$, where x – emerging situation, u – possible impact, and F – evaluation of actions u in the situation x. It is possible to suppose that the manager chooses to manage u^*, using some operator B so that $u^*=B\times x$. If the selected control is optimal, then the relation holds:

$$F(x,Bx)=F(E_t,Q)=\max F(t,x,u). \quad (10)$$

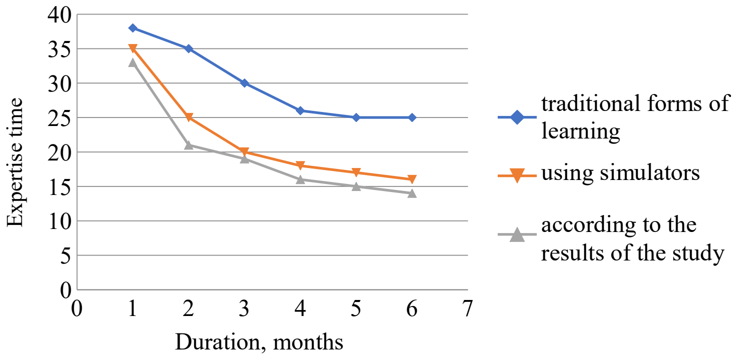

Fig. 3. Comparative analysis of the time to execute the algorithm of practical work of the operator of an automated workplace of the production process

To evaluate the proposed methods, it is proposed to determine the costs of practical training of a workstation operator in the production process using a simulator based on artificial intelligence.

Fig. 4 shows the results of the study of the simulator efficiency index F. When the indicator E_t (training time) decreases, the indicator F increases due to the fact that the costs directly for the training itself decrease. When the indicator Q (the indicator of the adequacy of the simulator) increases, the indicator E_t (training time) decreases.

Based on the above, it should be noted that the higher the Q index (the adequacy index of the simulator) of the technical systems simulator, the lower the costs of training the corresponding operator. The implementation of calculations according to formula (10) and the results of the well-known study [20] is given in the form of a dependence (Fig. 4).

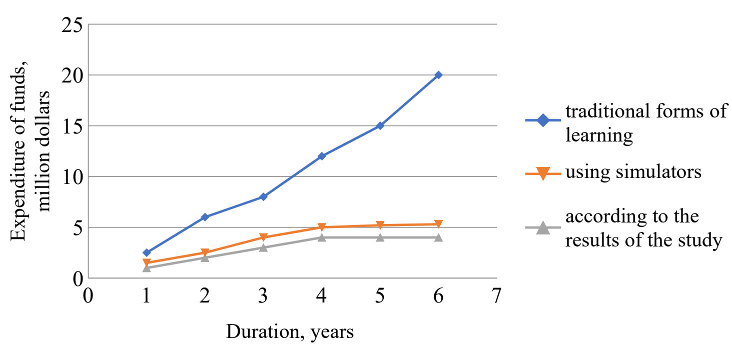

Fig. 4. Comparative analysis of costs for practical training of an operator of an automated workplace of a production process

Therefore, according to the results of the analysis of the obtained dependencies (Fig. 3, 4), it can be noted that the application of the methods proposed in the study allows to reduce the time for training operators and reduce the costs of practical training (for the training period).

6. Discussion of the results of developing a method for automatic control of monitoring means for information protection objects

The research proposes the results of developing a method for assessing the effectiveness of technical systems' computer dynamic simulators. The developed method is based on:

– the proposed functional scheme of reproducing the procedure for operating technical systems simulators (Fig. 1);

– efficiency criteria for evaluating the efficiency of technical systems' computer dynamic simulators, relations (1)–(5);

– qualitative indicators of training with the involvement of simulators, the ratio (6)–(9).

The developed method allows to estimate the required time for acquiring training skills and abilities, taking into account the required level based on the results of completing tasks both with and without the use of simulators.

A feature of the proposed method is the developed simulation model – a formalized scheme for reproducing the procedure for operating technical systems simulators (Fig. 1). At the same time, the use of artificial intelligence procedures that need to be trained is proposed. This approach provides for the adjustment of the simulator operation algorithm depending on the operator's practical training. The advantage of this study is the involvement of artificial intelligence in controlling the training algorithm with the involvement of the simulator to improve the quality of operator training. The advantage of this study compared to the work [8], which investigated the use of dynamic systems simulators, is the development and evaluation of the proposed indicators of the quality of training algorithms for practical work. Compared with previous studies, where the results of the analysis of open-source dynamic simulators [10] were proposed, this study allows to assess the effectiveness of using simulators in practical training of operators. The advantage of this study compared to the work [16], which considered the integration of artificial intelligence with dynamic simulators of energy systems, is the complexity of the study. The work proposes a simulator that corresponds to only one technical system - energy. This study is universal and the developed method allows to evaluate different simulators of different real technical systems.

The limitations of this study are the set of statistical data on the characteristics of simulators of real technical systems, which are in the public domain. This is mainly due to the strict specificity between the developers of simulator complexes and systems. To form an adequate set of such data, it is necessary to conduct an analysis of the array of characteristics of modern technical systems' simulators. At the same time, the study proposed to use the characteristics of well-known simulators, which are widely used in driver training, to verify the results obtained.

The disadvantages of this study are the accepted assumption about the technical serviceability of the simulators. At the same time, the study did not take into account the possibility of introducing a malfunction into the simulation of the functioning of the technical system to work out the algorithm of actions in an emergency situation. This should also be attributed to the shortcomings of the presented study. Although, it should be noted that the involvement of artificial intelligence procedures allows the introduction of a malfunction into the simulation of the functioning of the technical system. But such a simulator is already a training complex of a higher level of training and can be used in advanced training courses.

The prospect of this study is to develop criteria for assessing the effectiveness of technical systems' computer dynamic simulators that do not have a clear training algorithm. Such simulators train operators to respond to possible emergency situations that are not clearly spelled out in the management comments - they contain elements of uncertainty. However, such a study may face the problem of collecting statistical data on the characteristics of the simulators to verify the adequacy of the proposed criteria.

7. Conclusions

1. The scheme of reproducing the procedure of functioning of technical systems' simulators using artificial intelligence is substantiated. A feature of the developed scheme is the proposed procedure for constructing and studying a simulation model that reproduces the real processes of functioning of a technical system in a simulator. The simulation model of a real technical system through the use of the function of artificial intelligence allows to improve the realism of the simulator. This is explained by the fact that the use of simulators with artificial intelligence will allow for a more realistic imitation of the processes of functioning of a real technical system.

2. The proposed criteria for assessing the effectiveness of technical systems' computer dynamic simulators provide a justification for the potential possibilities of using the simulator system in the process of practical training and the formation of an assessment method. The proposed approach to assessing the effectiveness of technical systems' computer dynamic simulators allows comparing both existing simulators and conducting a comparative analysis of promising intellectual simulators using new information technologies based on artificial intelligence.

3. The analysis of the verification of the proposed criteria and the method for assessing the effectiveness of technical systems' computer dynamic simulators showed that the use of intelligent complex simulators (simulators) based on artificial intelligence not only reduces the time required for practical operator training, but also provides a reduction in financial costs by 40 % in the first year of using the simulator complex. The proposed approach to building computer dynamic simulators using artificial intelligence systems provides increased realism in simulating real processes in modern technical systems. In addition, it provides the ability to form and maintain the necessary level of practical work skills among operators (crew members, shift members), intensification of the training process of operators, and objectivity in assessing the level of training of crews (shift members).

Conflict of interest

The authors declare that they have no conflict of interest regarding this study, including financial, personal, authorship, or other, that could influence the study and its results presented in this article.

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The study was conducted without financial support.

Data availability

The manuscript has no associated data.

Using artificial intelligence tools

The authors confirm that they did not use artificial intelligence technologies when creating the presented work.

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