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RISK ASSESSMENT OF THE OPERATION OF AVIATION MAINTENANCE PERSONNEL TRAINED ON VIRTUAL REALITY SIMULATORS

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Conducting a safe briefing is essential to educate aircraft maintenance personnel, who very often encounter various unexpected and dangerous incidents. Their reaction to situations should be quick and adequate. To train aircraft maintenance professionals who cannot be practiced in real life due to high cost, danger, time or effort, virtual training seems like an obvious choice. This paper is devoted to the development of a calculation algorithm for assessing the risk of actions taken at the aircraft repair site, which was implemented in the training version of the virtual reality (VR) simulation. It includes a number of factors and elements that form the simulation scenario, influencing the degree of its complexity and the assessment of the performance of each exercise. Various components of the algorithm are presented, which allow assessing the skills of students of aviation specialist courses. The criterion for the acceptability of the developed algorithm is the correct assessment of the student's skills in the course of training.

Keywords: digital model, virtual reality, algorithm, 3D models, aviation technology

1. Introduction

Widely developed areas of application of virtual reality (VR) technology are mainly medicine, education and entertainment, as well as individual elements of production processes, robotics and data visualization (Velev and Zlateva, 2017). Of particular note is the training modeled in a three-dimensional environment (Muñoz *et al*., 2020), which covers a wide range of activities (Nedel *et al*., 2016; Cabral *et al*., 2016; Hament *et al*., 2017; Carruth, 2017). Delivering training in virtual reality (VR) is a flexible and effective way to improve and acquire skills.

VR technology solutions are also used in the field of emergency response. The high potential of the technology makes it possible to conduct training activities related to, for example, firefighting. The conducted studies have shown the need to continue work to identify methods for transferring the skills

acquired during virtual reality training in the scenario of real incidents and to assess the potential risks associated with frequent training in an exciting and physiologically simulating virtual environment (Engelbrecht *et al*., 2019). Virtual reality technology allows the creation of infinitely large and complex learning scenarios, allowing you to perform activities that would require huge hardware, financial and human resources in real life. At the same time, the quality of education does not differ from traditional education (Smith and Salmon, 2017). The results of studies based on both methods showed that listeners prefer 3D visual learning in virtual reality, while a comparison of the level of learning in both groups showed no difference. Other studies have shown that virtual reality and augmented reality courses produced better educational outcomes than traditional training in terms of speed of action as well as the number of mistakes made. It was found that the ambulance workers who participated in the training improved their skills in terms of the speed of completing tasks by 29% (Koutitas *et al*., 2021). The use of a virtual reality based method for training is especially applicable in areas where the cooperation of human teams in various fields is required, which is associated with high economic costs and high risk.

Of particular note is VR training used in response to natural and construction disasters and fires (Li *et al*., 2020). The use of these methods allows the user to immerse themselves in building subconscious patterns that will be used in case of crisis situations (Mitsuhara *et al*., 2019; Sungjin, 2020; Chittaro and Buttussi, 2015; Dang *et al*., 2021). Such arrangements are described in particular with regard to tasks carried out under emergency conditions (Xu *et al*., 2018), as well as in relation to education and training systems implemented by the military sector (Myunghwan *et al*., 2019; Bourhim and Cherkaoui, 2020). Another group of users are customs and police who are involved in high-risk events (Kavakli, 2006; Zhu and Li, 2021).

A strong sense of presence and effective virtual reality immersion ensure that learning takes place in a safe and controlled environment. Interns have the opportunity to prepare and "practice" on a variety of topics and sequences before they get to work in the real world. This leads to a significant increase in skills, at the same time they are more confident and use tools more efficiently, increasing their practical effectiveness and reducing possible material or time losses.

However, the instructor is responsible for effectively teaching the trainees, not forgetting the areas that present the greatest difficulty when it comes to the actions taken. It is especially important to include elements in the simulation that represent threats that the user will encounter in real life, and evaluate the risk of their actions depending on the threats presented. A virtual assessment system that takes into account the complexity of learning in a simulated 3D environment has proven to be useful in evaluating learning outcomes.

This training proposal is intended primarily for aircraft maintenance professionals and provides a risk assessment of actions taken at the aircraft repair site based on a mathematical algorithm implemented for VR learning technology. As a result, the teacher receives assistance in evaluating students, and performing an exercise in virtual reality makes it possible to increase the efficiency of the educational process and transfer knowledge to students in accordance with the rules, standards and Kazakhstani legislation.

This solution guarantees an objective and repeatable assessment by the specialist, which until now has been carried out in a discretionary manner (Garcia, 2019) or focused on only one parameter, such as reaction time (Kwegyir-Afful, 2022). At the same time, the algorithm allows the creation of original scenarios adapted to current needs and legal regulations, and is more versatile than other learning systems based on a strictly defined scenario. As a result, the teacher receives assistance in assessing students. Performing an exercise in virtual reality allows you to increase the effectiveness of the training process.

The described algorithm was created and adapted to the needs of training aircraft maintenance personnel in the field of aircraft repair, but the mathematical foundations used make it easy to apply in training dedicated to emergency services and other types of aviation services. The expansion of the target group will form the basis for further development work.

2. Materials and methods

The combination of VR visualization with a risk assessment module allows you to introduce a causal sequence into the learning algorithm. Only the combination of these two elements makes it possible to conduct an assessment and, thus, is effective in training specialists in cases of danger (Kwegyir-Afful, 2022). The basis for the development of the corresponding calculation method was the International Standard ISO 31000 "Risk Management – Guidance". In accordance with the standard, risk identification consists in the search, diagnosis and description of risks and includes the identification of risk sources, incidents, their causes and potential consequences. This identification is based, among other

things, on theoretical information and expert opinion. In risk analysis, an important aspect is the risk criteria, which are a reference system on the basis of which the risk is assessed. Risk criteria can be defined based on requirements, standards, rules and other necessary dependencies. As part of risk identification, the causes of this risk are also indicated - risk criteria (factors). Decisions made should be based on safe assumptions, that is, without negative consequences. On the other hand, the activities must also include certain risky behaviors, but in a safe manner. This largely depends on the degree of confidence in decision making. Thus, a solution that assumes the achievement of a previously established assumption can be considered a safe solution.

One specific risk factor is the decision-making process. In the question under consideration, this aspect is related to the consequences of the decisions taken by the aircraft maintenance specialist for his / her further actions, i.e. whether the current decision will reduce or increase the risk.

In the subject edition, direct application of the ISO 31000 recommendations is not possible due to the specificity and complexity of the subject matter. Algorithm development is based only on standard risk analysis guidelines. The risk diagram of the actions of aircraft maintenance specialists at the aircraft repair site is shown in Figure 1.

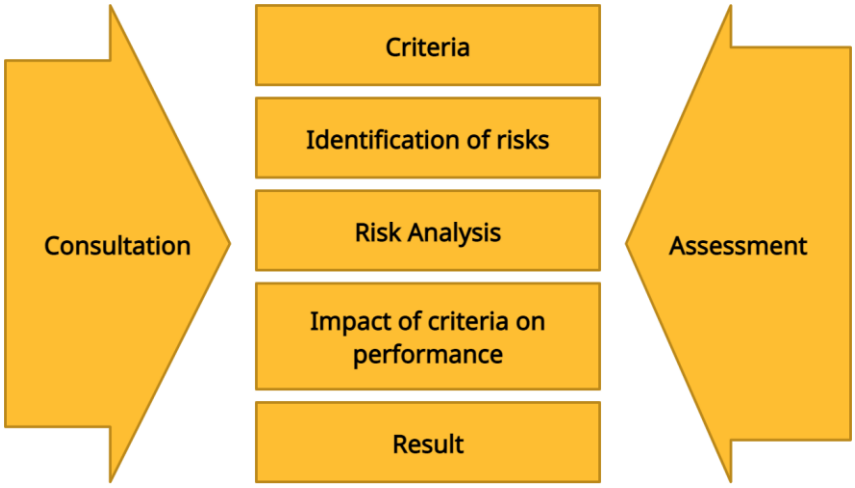


Figure 1. Flowchart of the risk management process

The presented analysis concerns the actions of aircraft maintenance specialists at the aircraft repair site. For this purpose, a risk matrix was adopted.

The risk matrix model focuses on two aspects:

The level of complexity of the scenario (*N*), which is associated with the method of performing each action, depending on the conditions for performing these tasks (actions), their number, and also takes into account the change in the intensity of one or another factor.

Priority decision making (*P*) is an assessment of the decision made in relation to the actions being implemented, taking into account the priority, i.e. the sequence in which they are carried out, including in the context of "changes" factors (amount, intensity) that may be introduced during the simulation, which gives rise to the need for additional actions.

Mathematically, a matrix is the Cartesian product of two sets; *P* and *N* were given for our analysis. Graphically, the risk matrix is a square containing 25 colored cells (5×5). In this algorithm, implemented to simulate training in virtual reality, the risk matrix is the final and, at the same time, the key calculation factor. The result is assistance to the teacher in terms of assessing the student's skills. First, an *N* and *P* rating (Table 1) from 1 to 5 should be assigned to the resulting percentage levels: 0-20% (negligible), 21-40% (slight), 41-60% (moderate), 61-80% (severe) and 81-100% (catastrophic). The risk score should then be "plotted" (Table 2) at the intersection of the two values. On this basis, the risk level and therefore the student's skills can be classified and evaluated.

Green – low level.

Yellow – medium level.

Orange – high level.

Red – extreme level.

Table 1. Level *P* and *N*

Level *P* and *N*	**Percentage ranges**	**Level (Definition)**
(*P* and *N*) 1	0-20%	Minor
(*P* and *N*) 2	21-40%	Small
(*P* and *N*) 3	41-60%	Middle
(*P* and *N*) 4	61-80%	Serious
(*P* and *N*) 5	81-100%	Catastrophic

Table 2. The risk matrix of the actions of an aircraft maintenance specialist performing actions at the aircraft repair site

P*/*N	**(*N*) 1**	**(*N*) 2**	**(*N*) 3**	**(*N*) 4**	**(*N*) 5**
(*P*) 1	1	2	3	4	5
(*P*) 2	2	4	6	8	10
(*P*) 3	3	6	9	12	15
(*P*) 4	4	8	12	16	20
(*P*) 5	5	10	15	20	25

It should be noted that *P* with a value of 0% refers to the case when a student of specialized aircraft repair courses performs all tasks in the correct sequence. On the other hand, a value of 100% means that the tasks were not completed or that the participant did not meet the boundary conditions set by the teacher. For *N*, a value of 0% refers to the start of the simulation, time 0.00. Each subsequent value up to 20% refers to the least complex scenario, and 100% to the most complex scenario.

The use of a two-dimensional risk matrix is one of the main ways to determine the hazard associated with the implementation of a potential activity. The standard solution for this type of project is the Ideal Solution Order Preference Technique (ISOPT), according to which the best alternative should have the shortest Euclidean path to the ideal solution and the furthest from the worst solution (Simić *et al*., 2021). A solution of this type is optimal in the case of symmetric X×X matrices, in which the increase in risk can be considered as a linear value. In the proposed algorithm, the use of this type of solution would be inappropriate, since in the presented scenario, the tasks have different levels of significance. Thus, the use of the ISOPT solution would make it difficult to implement a mathematical model that takes into account the correct execution of tasks, movement in VR space, and the sequence of tasks. At the same time, the mathematical basis of the algorithm, which consists in multiplying the level of risk present in the scenario and the correctness of the tasks, is popular among this type of application; in modern literature, it is described as the "Singapore method/model" (Kovačevića *et al*.,2019; Goyal *et al*., 2022; Fejdyś *et al*., 2022).

3. The purpose and objectives of the research

This section presents the purpose of the work and the input data that were included in the calculation method. The purpose of the work is to support the process of training aircraft maintenance specialists performing actions at the aircraft repair site by assessing the tasks performed and the impact of the decisions made on subsequent actions. In order to develop the calculation method as accurately as possible, we had to take into account all the modeling factors necessary for creating scenarios, and the hardware capabilities that determine various options for performing exercises in virtual reality. The paper considers the factors that make up simulation visualization, scenario creation, such as circumstances, status, actions, inaction, external and internal events, and other conditions that may or may not affect the risk of errors. The factors influencing the scenario are expressed on a three-point scale, where 1 is the factor representing the average difficulty in learning, 2 is the average, and 3 is the greatest difficulty. The categories of factors (main factors) include: infrastructure, conditions, number of aircraft parts, helicopter units, tools for aircraft parts and others (for example, kinetosis, time of day). The possibility of changing the "intensity" of some factors, for example, fogging, has been taken into account (from 0% – low level to 100% – high level). Each major factor group includes a sub-group consisting of an exhaustive list of items such as helicopter assembly, right hand or left hand threads and bolt torques. They were assigned certain points (so-called weights). This has a significant impact on increasing the complexity of the simulation (scenario) and may ultimately affect the final assessment of the entire training. In addition, the sum of the individual weights is assumed to be 1 (100%).

The methodology also takes into account the tasks (exercises) developed by the Joint-Stock Company Aircraft Repair Plant No. 405, which must be performed by a student of special aircraft maintenance courses. This made it possible to check not only which tasks should be performed, but also in what sequence. Considering all the possibilities of creating simulations, the authors identified the option when tools are needed for aircraft parts.

Working with avionics tools and events related to them is a special case foreseen during training.

Depending on the purpose, the following types of tool kits are installed (Table 3):

1EI – for the maintenance of aircraft and helicopters, as well as autonomously based groups of aircraft, by technical crews and teams;

2EI – for the maintenance of aircraft and helicopters by the engineering and technical staff of squadrons or aviation technical bases;

3EI – to perform routine maintenance and repair of aircraft and helicopters by the technical and operational part of the regiment, military aviation repair shop or a separately based air squadron.

Table 3. Tool kit numbers and their purpose

Kit type	Set number	Set assignment
1EI	1	For the aircraft technician (flight engineer, senior mechanical technician)
2EI	2	For aircraft (helicopter) and power plant (airframe and fuel systems, landing gear and hydraulic systems, control systems, household equipment, special equipment, means of emergency escape of the aircraft)
	3	For electrical equipment and electronic automation
	4	For instrumentation and photographic equipment
	5	For oxygen equipment
	6	For radio electronic equipment
	7	For aviation weapons
	8	For maintenance of the sighting-pilot-navigation complex
	9	For operational and intermediate airfields
	10	For metalwork and mechanical works
3EI	11	For aircraft (helicopter) and power plant (airframe and fuel systems, landing gear and hydraulic systems, control systems, household equipment, special equipment)
	12	For aviation weapons
	13	For electrical equipment and electronic automation
	14	For instrumental photographic equipment
	15	For oxygen equipment
	16	For radio electronic equipment
	17	For flight information collection and processing systems
	18	For aircraft escape aids
	19	For work on the sighting-pilot-navigation complex
	20	For metalwork and mechanical works

In some cases, it is allowed to include in the 1EI kit the necessary tool kits from the 2EI kit.

For educational purposes, it is assumed that these toolkits are defined on a 3-level scale, where 1 is low, 2 is medium, and 3 is high.

The action at the aircraft repair site with a set of tools is associated with the so-called "life threat" presented in the simulation. This is due to the fact that the student must comply with the highest safety measures when modeling (including approaching aircraft parts, trying to determine the type of unit, etc.). The degree of risk for a student's error takes only two values – 0 or 100, where 0 means that the life and health of people on board the ship are in danger, people are in dangerous aviation equipment. Thus, the simulation is terminated. The value 100 refers to a situation where there is no risk to life and health and the simulation can continue.

In the case of several units in aircraft repair under different conditions, procedures based on separation or sorting are applied. The following breakdown has been applied:

– red signal – unit repair;
– green signal – the unit is in working condition;
– yellow signal – unit diagnostics;
– black signal – the unit cannot be restored.

This means that if a scenario during training involves several units of aviation equipment, “marked” in red, yellow and green, the trainee must start the repair first of all with a red signal. In addition, under these assumptions, an appropriate weight can be assigned:

– red – 3
– green – 2
– yellow, black – 1.

4. Materials and methods of research

The risk assessment of the actions of trainees of aircraft maintenance courses at the aircraft repair site is based on a mathematical algorithm implemented in the training VR technology. The method of calculating the virtual assessment of student behavior takes into account two main aspects. The first

concerns the evaluation of the actions performed. This value consists of completing tasks as well as completing them in the correct sequence. To check the sequence, the so-called priority of tasks is used. This allows you to give the same priority to several different tasks. Thanks to this order, for example, tasks related to the repair of several units with the same condition (color) receive the same priority. This relieves the student of ethical responsibility during the repair of parts. Checking the execution of tasks in the system is carried out by marking: "completed task" and "incomplete task". The system assigns number one to a completed task and zero to an incomplete task. Another component of the first aspect is the virtual life of a specialist during a simulation with tools for aviation technology.

The second aspect concerns the complexity of the scenario. The instructor must select factors from the system list when creating a virtual training environment. The complexity of the scenario implementation depends on the number of these factors and the level of their impact. With such diversification, the teacher, when creating a scenario for a more or less advanced group, receives information from the system about the complexity of the scenario.

The error of the employee's actions at the aircraft repair site is calculated as an instantaneous value for a given simulation moment, t. This allows you to identify the most problematic elements for students already in the learning process. The resulting risk consists of the risk of the specialist's actions during aircraft repair (R) and the instructor's assessment (O_I). The value of 0.4 or 40% of the final risk score refers to the score calculated by the algorithm, and the value of 0.6 refers to the teacher's score, which is 60% of the R_k score. This breakdown occurs because the teacher decides on the satisfactory completion of the training in the presented training, and only the teacher can evaluate non-standard tasks, such as a teacher-student interview.

The equation describing the final risk is presented below:

$$R_k = 0,4 \cdot R + 0.6 \cdot O_I, \tag{1}$$

where R_k is the final risk of the employee's actions at the aircraft repair site, O_I is the teacher's assessment, R is the risk of the employee's actions at the aircraft repair site.

The R-parameter in equation (1) is defined as the product of the probability of a rational action and the level of complexity of the scenario characterized by equation (2)

$$R = P \cdot N, \tag{2}$$

where R is the risk of an employee's actions at the aircraft repair site, P is the probability of performing rational actions, N is the level of complexity of the scenario.

The risk of a specialist's actions at the aircraft repair site (R) includes the probability of performing rational actions during training in virtual reality and the level of complexity of the scenario created by the teacher.

The level of complexity of the scenario consists of the so-called main factors. They were selected based on the experience of aircraft maintenance personnel to include the most important elements that affect the learning experience in virtual reality. From a mathematical point of view, this is the product of this factor and the expert weight assigned to it. The authors chose seven main factors (Table 4), which consist of elements with appropriate expert weights.

The formula that determines the level of complexity of the scenario (N) is presented below:

$$N = \left(\left(X_D + X_W + X_I \right) \cdot 0,1 + \left(Y_L + Y_O \right) \cdot 0,15 + \left(X_T + Y_A \right) \cdot 0.2 \right) \cdot 100\%, \tag{3}$$

where N is the level of complexity of the scenario, X_D is the "infrastructure" factor, X_W is the "conditions" factor, Y_L is the "number of aircraft parts" factor, Y_O is the "helicopter equipment units" factor, Y_a is the tools for aircraft parts, Y_T is "bolt torque" factor, X_I – "other" factor.

Training is conducted according to different scenarios. The main factors and elements are specific and differentiated "parameters" and, therefore, the main factors are divided into the following groups:

Group I – infrastructure, conditions, other;

Group II – bolt tightening forces;

Group III – the number of parts of aviation equipment, units of helicopter equipment, tools for parts of aviation equipment.

The difference between the groups relates to the method of calculation.

Group I is determined based on equation (4), which is the product of the sum of the weights of the individual elements present in the scenario and the product of the number of these elements and the largest weight, i.e. 3.

$$X_i = \frac{\sum_{i=1}^{n} x_i}{n \cdot 3}, \tag{4}$$

where X_i is a value that depends on this factor, x_i are the individual weights of the factor elements and $x_i \in \{1,2,3\}$, n is the number of factor elements.

Group II is characterized by equation (5). As in the previous case, there are weights and the number of individual elements.

$$Y = \frac{\sum_{i=1}^{n} y_i}{n \cdot 3} \cdot 0,3 + (1 - \frac{1}{n^2}) \cdot 0,7, \tag{5}$$

where X_i is a value that depends on this factor, x_i are the individual weights of the factor elements and $x_i \in \{1,2,3\}$, n is the number of factor elements.

Group III calculations take into account the weights of individual elements and their number, as shown in the following relationship:

$$Y = \frac{\sum_{i=1}^{n} y_i}{n \cdot 3} \cdot 0,3 + (1 - \frac{1}{n}) \cdot 0,7, \tag{6}$$

where Y_i is a value that depends on this factor, y_i are the individual weights of the factor elements and $y_i \in \{1,2,3\}$, n is the number of factor elements.

This group also includes the specific case of aircraft repair related to tools for aircraft parts. As mentioned earlier, conditions can affect the properties of some elements of technology. This issue also needs to be taken into account in the algorithm. The formula takes into account the weight of the condition element and the difficulty level of the material. This is shown in equation (7).

$$Y_i = \frac{\sum_{i=1}^{n} a_i}{n \cdot 3} \cdot S, \tag{7}$$

where Y_i is a value that depends on working with tools for aviation technology, a_i are the individual weights of the factor elements (depending on conditions) and $a_i \in \{1,2,3\}$, n is the number of factor elements, S is the dimension given in working with tools for aviation technology.

The issue of the threat to the lives of people in an aircraft is directly related to the issue of proper repair of aviation equipment. In the performance of their tasks, trainees and aircraft maintenance specialists of specialized courses must comply with certain safety standards, although it may happen that they find themselves in a dangerous area. This situation should also be included in the simulation. The degree of danger to human life is described by the following equation:

$$L = (1 - \frac{l}{100}), \tag{8}$$

where L is the degree of danger to people's lives (0 or 1), l is the value 0 or 100, where the first value refers to the situation in which a gross error occurred and people's lives are in danger. A value of 100 means that there is no threat to human life and health.

The second component of the algorithm relates to the assessment of the rationality of actions (P_1), which consists of an assessment of the performance of the task (O_z) and an assessment of the performance of the task with due priority (O_P). In addition, the evaluation of rational action includes two important points. The first is task completion and the second is the task sequence. Both problems have the same level of importance. The calculation is based on the following formula:

$$P_1 = \sqrt[10]{\frac{O_Z^{10} + O_P^{10}}{2}}, \tag{9}$$

The parameters O_z and O_P present in the formula are described in equations (10) and (11).

The task completion score covers the number of tasks completed by the listener and the total number of tasks in the script that needs to be completed.

$$O_Z = 1 - \frac{\sum_{i=1}^{n} C_i}{c}, \tag{10}$$

where O_Z is the assessment of task completion, C_I is the number of tasks performed by the specialist, c is the total number of tasks in the scenario during simulation.

Estimating the completion of a task with due priority refers to the sequence of tasks to be performed by a specialist, and is based on assigning appropriate priorities to tasks. A situation is acceptable when there are several tasks with the same priority. This allows you to assign the same priority to several different tasks, for example, tasks 1 to 5 can have priority 1, and tasks 6 to 10 can have priority 2. It does not matter in which order tasks 1 to 5 are executed. It is important that tasks 6 10 have not been completed before them. This allows you to create groups of tasks with the same level of importance. The O_P score is calculated based on the number of tasks completed in the correct sequence (G_I) and the total number of tasks completed during the simulation (g).

$$O_P = 1 - \frac{\sum_{i=1}^{n} G_i}{g}, \tag{11}$$

where O_P is the assessment of the correctness of the tasks execution according to the given priority. G_I is the number of tasks completed in the correct sequence by the student, g is the total number of tasks in the scenario.

The probability of a rational action takes into account the degree of danger to human life (L) and the assessment of the rational action given (P_1), as follows:

$$P = \sqrt[10]{\frac{L^{10} + P_1^{10}}{2}}. \tag{12}$$

Based on the obtained results P and the level of complexity of the scenario N, data can be obtained to determine the level of risk based on the risk matrix (Table 1-2). The mathematical algorithm for assessing the risk of aircraft maintenance specialists in virtual reality training simulations is shown in Figure 2 (Pirmanov *et al*., 2022; Astapenko *et al*., 2021).

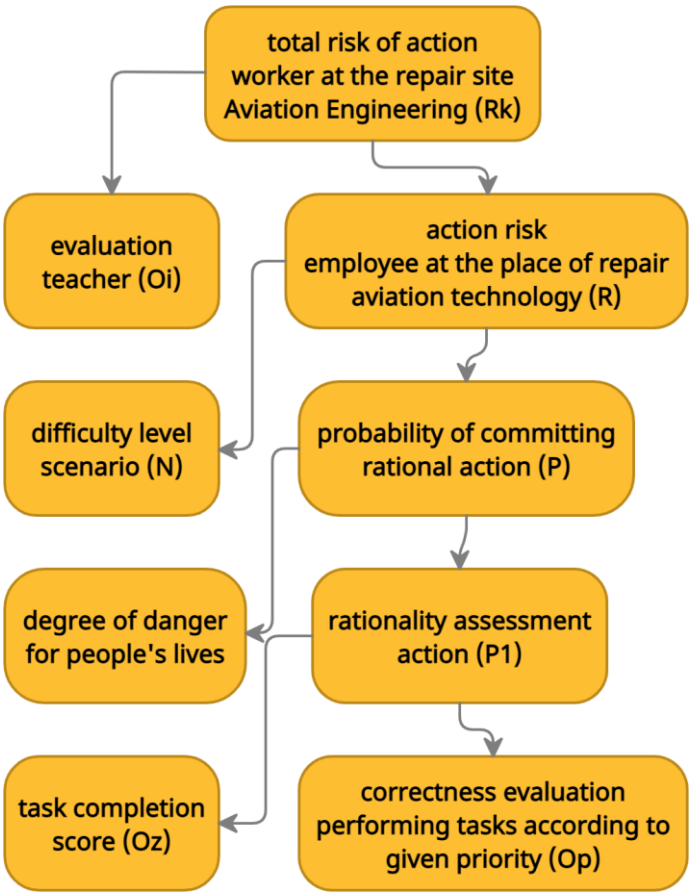


Figure 2. Block diagram of the algorithm

Table 4. Main factors and their weights

Name	Factor symbol	Weight
Infrastructure	D	0.1
Terms	W	0.1
Number of aircraft parts	L	0.15
Helicopter units	O	0.15
Tools for aircraft parts	A	0.2
Bolt torque	T	0.2
Other	I	0.1
Infrastructure	D	0.1
Terms	W	0.1
Number of aircraft parts	L	0.15
Helicopter units	O	0.15
Tools for aircraft parts	A	0.2
Bolt torque	T	0.2
Other	I	0.1

5. Algorithm verification

A scheme for calculating the risk assessment of actions taken at the place of repair of aviation equipment has been tested. For test scenarios, it is assumed that the level of complexity will be different. In addition, the possibility of incorrect execution of the task, incompatibility with its priority, that is, without observing the proper sequence, has been introduced. A variety of scenarios allows you to define a wider range of functionality of the algorithm, while showing how many components affect the complex course of learning.

On the basis of the obtained results, graphs of the probability of a rational action and time are constructed. Then, based on the risk matrix, the level of risk was assessed, reflecting the skills of the trainee.

Below is an overview of the three test scenarios and the results of the tests performed (Table 5-7).

Table 5. Scenario 1

Main characteristics	Elements
Infrastructure	The audience
	Laboratory
Terms	Without a teacher
	Without time
Another	Summer time
	day time – day
	Instruction – present
	Joystick Intensity – Medium
Detail of aeronautical engineering	Assembly
	Disassembly
Helicopter units	Valve H-5810-270
	Check valve 636100
Classes	Class 1
	Class 2
	Class 3
	Class 4

Scenario 1 difficulty level was 63% (value 4, Table 1). During the training, the student was required to perform 25 actions on the spot in the correct sequence. The result achieved is the completion of all tasks, taking into account the fact that in the first minutes of the simulation two tasks were performed out of the correct sequence; this is shown in Figure 3. Further actions were taken in accordance with the relevant procedures and the curve decreases over time. The end result of the probability of taking a rational action is 28% (value 2).

Table 6. Scenario 2

Main characteristics	**Elements**
Infrastructure	The audience
	Laboratory
Terms	Without a teacher
	Without time
Tools for aircraft parts	Present
Another	Summer time
	day time – day
	Instruction – present
	Joystick Intensity – Medium
Detail of aeronautical engineering	Assembly
	Disassembly
Helicopter units	Valve H-5810-270
	Check valve 636100
Classes	Class 1
	Class 2
	Class 3
	Class 4

Table 7. Scenario 3

Main characteristics	**Elements**
Infrastructure	The audience
	Laboratory
Terms	With a teacher
Another	With time
	day time – day
	Instruction – present
	Joystick Intensity – Low
Detail of aeronautical engineering	Assembly
	Disassembly
Helicopter units	Electric motor MV-1200
Classes	Class 1
	Class 2
	Class 3
	Class 4

Putting the values 4 and 2 into the risk matrix, we get the final result at level 8 (yellow color, Table 2).

Scenario 2 introduces an additional factor of working with tools for aircraft parts (Table 6).

Scenario 2 difficulty level was 73% (Table 1). Figure 4 shows the test results. During the training, the specialist had to carry out 30 events at the aircraft repair site in the correct sequence. 24 tasks were completed, four of which were completed incorrectly, and six tasks were not completed. Since the specialist was in the danger zone during the simulation, the training was interrupted. The situation occurred at the 17th minute of training. This is shown on the graph as a sudden increase in *P*. The end result is a 97% chance of taking a rational action.

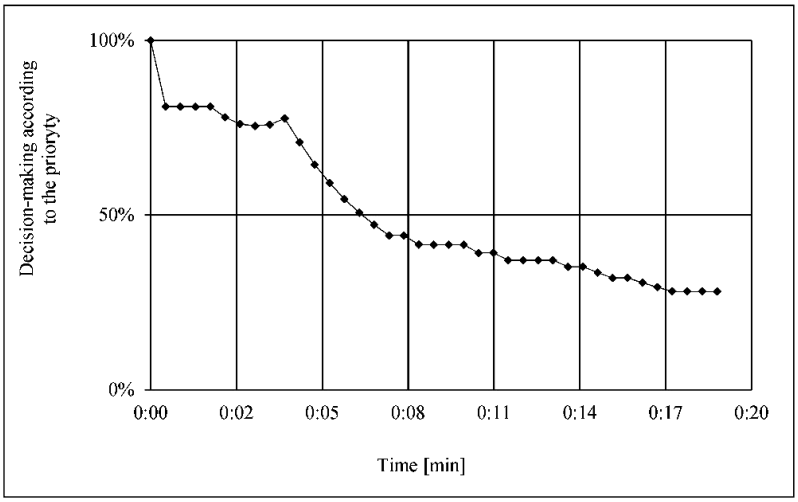


Figure 3. Graph of the probability of rational actions depending on the duration of the simulation in relation to scenario 1

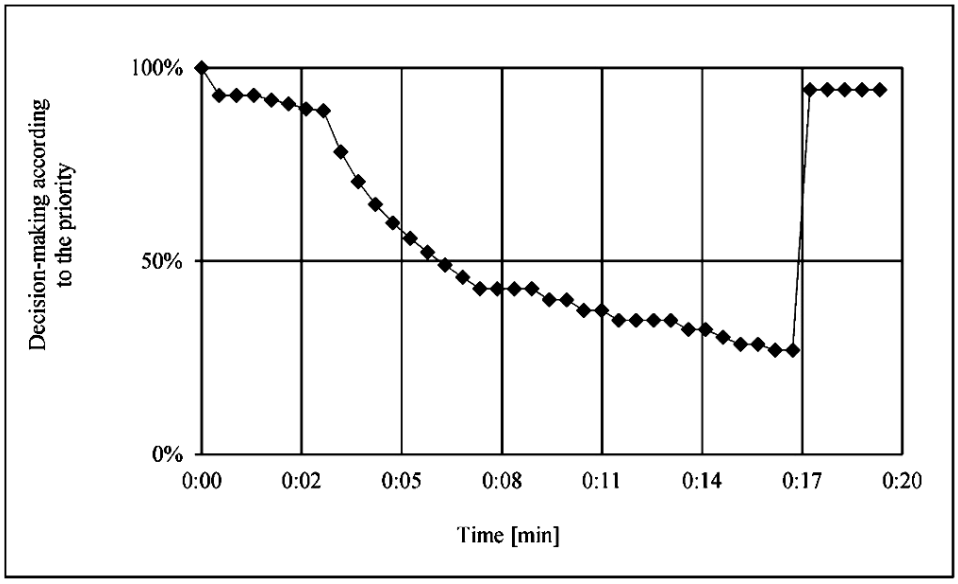


Figure 4. Graph of the probability of rational actions depending on the duration of the simulation in relation to scenario 2

Based on the risk matrix, a final score of 20 was obtained (red, Table 2).

When preparing scenario 3, the MV-1200 electric motor was taken into account (Table 7).

The level of complexity of the scenario was 75% (Table 1). The test results are shown in Figure 5. The training system involved performing 15 actions in the appropriate sequence. The participant completed nine tasks, one of which was completed in the wrong order. In addition, this task was not performed during the entire training period. For almost the entire period of training, the value of *P* was above 50%, reaching a high level.

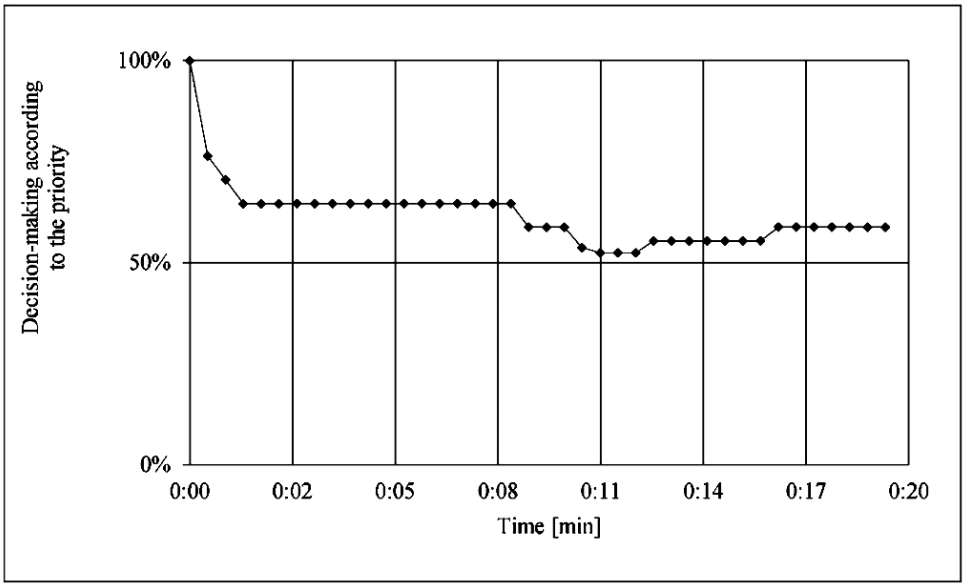


Figure 5. Graph of the probability of performing rational actions depending on the duration of the simulation in relation to the scenario

Risk assessment according to the risk matrix – 12 (orange, Table 2).

Figure 6 presents the results of the risk level assessment for three test scenarios, interpreted on the basis of the risk matrix. The level of complexity of a given scenario does not always imply an increase in risk assessment; an example is scenario 3. The same is true for the number of tasks.

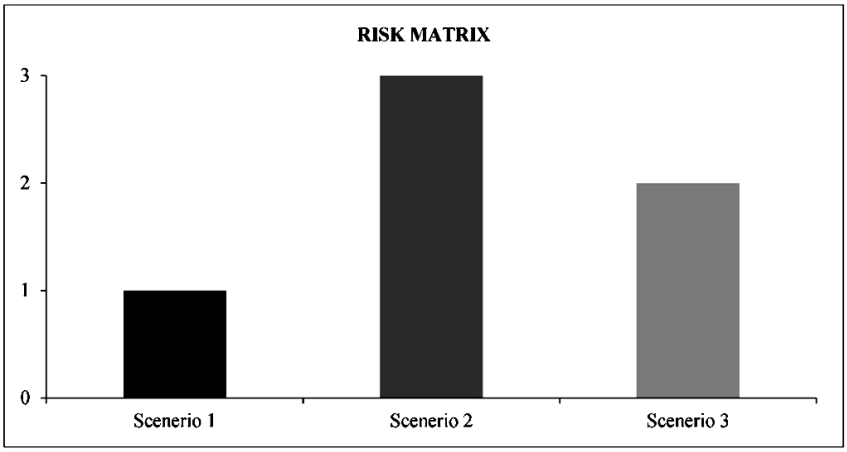


Figure 5. Assessing the risk level of test scenarios

The results of the simulations show that the developed algorithm is suitable for different types of scenario complexity, different tasks and different sequences of actions for any duration of the simulation. It also takes into account any changes to the simulation made during its execution. Thanks to this approach, the teacher can constantly monitor the level of complexity of the scenario, and therefore, check the performance of tasks by the trainee. In addition, it is a useful tool for improving the level of training.

In the future, the presented solution can serve as the basis for the analysis of different types of scenarios with the same level of complexity, which is very important in the process of training employees at the aircraft repair site.

In addition, after several simulations with the same tasks, the teacher will be able to identify the most difficult tasks for specialists and in the future pay special attention to these aspects in the educational process in order to increase the efficiency of the aircraft repair site. The use of an algorithm that evaluates the behavior of students in certain conditions when teaching in virtual reality may allow training to be carried out without the presence of supervisors.

6. Conclusions

This article presents a computational algorithm for assessing the skills of students in courses of aviation technology specialists in a virtual reality environment. It determines both the level of complexity of the developed scenarios and the assessment of the actions performed by the student during the simulation. This calculation method can be used for various types of training simulations, be it police, medical, fire or industrial simulations. The results of the developed algorithm are very promising, but in the future, the authors intend to test more scenarios in order to minimize the possibility of errors and contribute to the improvement of the developed algorithm. The developed algorithm allows using it in VR simulations of other life-threatening situations. The proposed algorithm can be implemented in training courses in the area of operations in hazardous or contaminated areas. This solution would be of particular benefit to emergency responders working in refineries and other centers of the chemical industry. Moreover, the mathematical basis of the algorithm makes it easy to adapt training to the needs of fire brigades, as well as police rapid response units. The next stage of development will be the expansion of the algorithm with further scenarios of events in which civil aviation employees can take part.

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