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Development and research of design methodology for digital training models of helicopter repair processes

D105 - Aeronautical engineering and technology

Degree thesis
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REGULATORY REFERENCES

The thesis uses references to the following standards:

Law of the Republic of Kazakhstan “On the Use of Airspace of the Republic of Kazakhstan and the Activities of Aviation” dated July 15, 2010 #339-IV.

Address of the Head of State to the People of Kazakhstan on September 2, 2019 “Constructive public dialogue is the basis of stability and prosperity of Kazakhstan.

“Nurly Zhol” for 2020 - 2025. Decree of the Government of the Republic of Kazakhstan dated December 31, 2019 #1055.

On Approval of the State Program “Digital Kazakhstan”. Decree No. 827 of the Government of the Republic of Kazakhstan dated December 12, 2017.

International Standard ISO 31000 Risk Management - Guidance. Second edition 2018-02.

INTRODUCTION

Relevance of the work

The aviation industry is one of the promising areas of economic growth of the Republic of Kazakhstan and includes a complex of enterprises implementing technological processes: production, maintenance and repair of aircraft, helicopters and aircraft equipment.

The most promising enterprise is JSC "Aircraft Repair Plant #405", which specializes in the production and repair of helicopters, and the second technological process is more than 80% of the production cycle.

Repair of helicopter equipment is accompanied by a number of problems: the obsolescence of technology, low level of automation, high requirements for compliance with workplace safety. But the most difficult is the procedure of training organization, because as a result the trainees need to assign practical and quality competences with minimum costs and maximum self-training without discontinuing the production of the instructor-mentor, as well as to provide control of mastering the training material, taking into account the risk of actions on the repair site.

Improving the quality of education is also dictated by the high requirements for flight safety in accordance with the law "On the use of airspace of the Republic of Kazakhstan and aviation activities". [1], international requirements to the standards and recommended practices of ICAO [2] and EASA [3], of which the Republic of Kazakhstan is a member.

At enterprises, repair of aviation equipment requires urgent implementation of digitalization to optimize the technological process, improve workplace safety, formation of a database of repaired objects and parts to calculate costs and forecast labor and financial resources. It is necessary to create a universal computer learning technology, in the form of software and pedagogical tool that can effectively not only solve the above problems, but also improve the quality of theoretical knowledge and practical competence, possibly through the use of virtual reality technology. Consequently, it is required to create scientific-theoretical foundations and methodological tools of digital transformation and modernization of not only the training processes of helicopter repair, but also others in the production cycle of the aviation industry.

Thus, based on the current state of the problem, dissertation research aimed at developing a methodology for designing digital training models of helicopter repair processes is currently very important and relevant.

The purpose of the dissertation work

The aim of the work is to develop theoretical and methodological approaches, scientific and practical recommendations on digitalization and improving the quality of theoretical knowledge and practical competencies in training based on advanced 3D-modeling and VR-virtual reality technologies on technological processes of repair of helicopter equipment.

To achieve this goal in the thesis the following **tasks** are solved:

1. Study of production cycles of aviation enterprises of the Republic of Kazakhstan, to identify a list of problems of the technological process of repair of aviation equipment that require urgent resolution with scientific research.

2. Research and analysis of digital tools to solve the production problem of determining the basic requirements for the development of digitalization of aircraft repair enterprises.

3. Research and analysis of computer-based educational technologies and the formation of a list of requirements for effective professional development in the production of helicopter repair.

4. Development of the conceptual apparatus of digital modeling, classification and structure of the model, forming realistic objects or processes based on 3D-modeling technologies, VR-virtual reality and artificial intelligence, with the transfer of dynamic influences and reactions of its human perception organs.

5. Development of scientific-theoretical support of digital training models required for the design: mathematical, algorithmic, information-production, hardware-software.

6. Development of scientific-applied support necessary for the practical implementation of digital training models (hereinafter - DTM) for helicopter repair.

7. Development of a method and algorithm for calculating the assessment of practical competencies of aviation engineering course trainees in the VR virtual reality environment with the level of complexity of the scenarios developed and the assessment of actions.

8. Development of software and methodological support in the form of a set of documentation and software applications aimed at the development and application of DTM with the use of effective software applications and training and methodological regulations.

9. Development of technology and requirements for the implementation of digital learning models in a manufacturing enterprise.

10. Creating client-server software logic that allows management from a single server by multiple connected clients and includes 3D model databases and VR virtual reality applications.

11. Approbation by implementation of DTM {21} - Emergency Power On Valve GA-59/1 - on the basis of JSC “Aircraft Repair Plant #405”.

Research methods

The methods of analytical research, system analysis, mathematical and computer modeling, mathematical statistics, classification, programming and set theory and experiments were widely used to solve the problems set in the thesis research.

During the experimental part of the work were actively used design tools 3D-models and applications VR-virtual reality, automation of mathematical calculations and tools to visualize the results of research using computer programs *Solid Works, Blender3D and Unreal Engine 4.*

Expert opinions and recommendations of leading specialists in the field of helicopter repair were used during the research and to develop the methodology.

The subject of the study is the improvement of digitalization tools and training of helicopter repair processes.

The object of the study are digital models based on 3D - modeling and VR - virtual reality technologies for digitalization and training in helicopter repair.

Scientific novelty. The most significant new scientific results contained in the dissertation work are as follows.

1. Structure of the digital training model of the repair process, including input data input in a digital format, construction and processing of 3D models of inseparable parts and tools, creation of VR - virtual reality with control and evaluation functions and technical regulations.

2. Creation of a design method of a database of 3D models of photorealistic quality of parts, tools and units of aircraft equipment, as well as their textures for further use. The need for photorealistic quality is to reduce the influence of the human factor on the risks associated with maintenance and repair.

3. Creation of the VR database design method - virtual reality of the repair process of aviation equipment units with control and evaluation functions and technical regulations.

4. Technology of designing and layout of hardware and software complex of interactive training programs based on 3D-modeling technology and VR - virtual reality on technological processes of aircraft repair.

5. A conceptual general approach to the development of scientific-theoretical and applied support of digital training models for helicopter repair is proposed.

6. Development of the structure of “The training complex “Repair of helicopters” and software and methodological support for the design of experimental applications to create interactive training programs based on 3D-modeling technology and VR - virtual reality, simulation of standard and abnormal operating situations for practical training.

7. Development of design methodology for interactive training programs based on methods and algorithms for converting design documentation of aircraft units and assemblies into semblance of real objects.

8. Method and algorithm for calculating the assessment of practical competencies of the aviation engineering course trainees in the VR - virtual reality environment with the definition of the level of complexity of the developed scenarios and assessment of the trainee’s actions during the simulation.

Practical Significance.

The practical significance of the work consists in the possibility of using the results obtained in the study to build digital and automatic systems for the aviation industry, allowing to optimize technological processes, improve workplace safety, form a database of repaired parts and units, to predict labor and financial resources.

Digital transformation based on the use of DTM allows you to create a universal computer-based learning technology that can effectively improve the quality of theoretical knowledge and practical competencies.

The results of the presented research make it possible to propose new effective technologies for repair of transport equipment of wide profile, as well as to develop decision support systems for human personnel, aimed at reducing the risk of errors and increasing attention.

The proposed structure of the digital training model and training complex allows you to effectively implement in practice the process of digital processing of 3D-models and the development of VR applications - virtual reality for further training and application in intelligent methods of information processing.

The comprehensive approach to digitalization and improvement of the quality of theoretical knowledge and practical competence in technological processes of helicopter repair presented in the thesis research can be applied in other spheres of human activity related to the operation and production of complex technical systems with man-machine interfaces.

The proposed training complex “Repair of helicopter equipment” has the ability to expand its functionality, including building databases, forming expert opinions, to include various quantitative and qualitative characteristics.

Linkage to government programs

In the Address of the Head of State to the people of Kazakhstan “Constructive public dialogue - the basis of stability and prosperity of Kazakhstan” Astana, Akorda, 2019 [4] President Kassym-Zhomart Tokayev drew the attention of the executive branch to the full and high-quality implementation of the State program of infrastructure development “Nurly Zhol” for 2020 - 2025, approved by Decree No. 1055 of the Government of Kazakhstan on 31 December 2019 [5], which states that effective modernization will affect all transport infrastructure.

The state program “Digital Kazakhstan”, approved by the Decree of the Government of the Republic of Kazakhstan #827 of 12.12.2017 [6] involves accelerating the pace of economic development of the RK and improving the quality of life through the use of digital technology in the medium term, as well as creating conditions for the transition of the economy of Kazakhstan to a fundamentally new development path, ensuring the creation of the digital economy of the future in the long term.

The proposed methodology of designing digital training models of helicopter repair processes is consistent with the concept of development of the aviation industry of air transport in terms of ensuring the safety of aircraft flight and meeting the needs of the economy of the Republic of Kazakhstan, individuals and legal entities in aviation services.

Scientific research presented in the dissertation work was conducted within the grant funding of the MES RK on the theme “AP08857126 - Development of a set of interactive training programs on technological processes of repair of aircraft equipment”.

The thesis statements put to the defense.

1. Comprehensive approach to digitalization and improving the quality of theoretical knowledge and practical competencies on the basis of 3D-modeling and VR-virtual reality technologies on technological processes of helicopter repair.

2. The design process of the DTM in the form of VR-virtual reality application for helicopter repair with control and evaluation functions and technical

regulations, including input data input in digital format, construction and processing of 3D-models of fixed parts and tools.

3. Mathematical model of helicopter repair center and design algorithm.

4. Scientific-theoretical and applied support of helicopter repair DTM for their research and design.

5. Technology of designing training complexes based on the helicopter repair center with a database of parts, tools and assemblies based on artificial intelligence technology, 3D modeling and VR-virtual reality to provide practical competencies with high ergonomic indicators: minimal financial costs and time involvement of instructors-mentors, independent learning, control of learning material with the risk of action on the repair site.

6. The structure of the "Training complex Repair of helicopter equipment" and software and methodological support for the design and operation of interactive training programs based on the DTM.

Approbation of the work.

The results of the thesis research were implemented in the training process of JSC "Academy of Civil Aviation" and in the production of LLP "ST Integrator Company" to improve the quality of products, as well as taken into account in the development of strategic development plan for the application of the developed digital model for helicopter repair training on the technological base of LLP "ST Integrator Company" until 2025, which aims to improve the reliability analysis, diagnosis and implementation of VR software tools in the aviation security system.

The main results of the thesis research were presented and discussed at: V-th International Scientific-Practical Conference "Creative Potential of Youth in Solving Aerospace Problems" (Baku, Azerbaijan, 2020).

Publications.

The main results of the thesis research are reflected in 11 scientific papers, including 7 articles published in the editions recommended by the Committee on Quality Control in Education and Science of MES, 2 articles in international scientific journals indexed in the database Scopus and Web of Science, in the works reflected in the proceedings of international scientific conferences, as well as in international and national peer-reviewed scientific journals, including specialized in the field of aviation engineering and technology.

Author's personal contribution.

The conceptual approach to digital modeling, the structure of digital training models, as well as the main experimental and theoretical results obtained in the course of the thesis research were obtained by the author independently. In the published scientific works as a part of the team of co-authors, the main contribution to the obtaining, generalization and analysis of the achieved results belongs to the applicant.

Dissertation Structure.

The thesis has a classic structure: an introduction, the main part (five chapters), the conclusion, a list of references and an appendix. The work is set out on 120 pages of computer text, includes 47 figures, 11 tables and 100 titles of bibliographic sources.

The main results of the research.

The thesis research provides a theoretical justification and proposes a solution to an urgent scientific problem requiring the creation of methods and technologies of digitalization and automation for quality training with the assignment of high theoretical knowledge and practical competence, optimization of all stages of the production cycle, improving workplace safety, forming a database of repaired units, tools and parts for cost calculation and forecasting labor and financial resources.

Through the use of computer-based learning technologies based on 3D modeling and VR-virtual reality it is proposed to create a digital learning environment with intuitive interaction in real time.

The conceptual apparatus has been developed and the fields of application of educational technologies in the aviation industry, as well as areas of training for the training of installation and repair specialists have been determined. The model and description of helicopter repair technological process operations and application development stages are offered.

A conceptual approach to the classification of digital models is formed and a new fourth type of model is proposed at the conceptual level, forming realistic objects or processes in which dynamic influences and their reactions are transmitted to the person through his perception organs - sensations.

The structural scheme of training digital models of the DM-4 in the repair of helicopters has been developed.

A characteristic scientific-theoretical support of the DTM process of helicopter repair, confirming the systematic and methodological approach to the proposed digitalization, is proposed.

Mathematical support for DTM is presented in the form of a mathematical model, in which the input data of parametric and functional nature at the output is formed by the VR-virtual reality software application in the form of a complex function.

Algorithmic support is a step-by-step text and graphical representation of development and functioning of DTM of helicopter repair processes. The peculiarity of this type of software is that it takes into account expert recommendations of industry specialists and placement of information in databases of 3D-models and VR-virtual reality applications.

Information and production support is designed for optimal allocation of infocommunication and technological resources of the production cycle to ensure the effective functioning of the DTM.

The hardware and software of the DTM include a selection of modern technical means for high-performance and high-efficiency implementation and operation. The structure includes elements built on technologies in radio electronics and telecommunications, programming, visualization, artificial intelligence, psychology, and pedagogy.

Developed the provision of DTM, associated with the development of a method and algorithm for calculating the assessment of practical competencies, training to repair aircraft equipment in VR - virtual reality environment. This solution allows its use in VR-simulations of other life-threatening situations.

Proposed software and methodological support, which is a set of documentation and procedures for the implementation of DTM processes using effective software applications and educational and methodological complexes. The result of this type is provided software module VR-virtual reality, technical documentation - regulations for the development and use/operation of applications.

By order of JSC “Aircraft Repair Plant #405” a training complex “Repair of helicopter equipment” was developed, which includes 25 digital models of helicopter aggregates subject to overhaul, current and local repairs.

The complex is a relational database, based on the scientific and theoretical principles of relational algebra: tables, relationships, rows, columns, primary key, relational algebra, etc.

Describes the implementation of the DTM {21} - Emergency Power On Valve GA-59/1, which is one of the important elements of the helicopter.

SYMBOLS AND ABBREVIATIONS

JSC	-	Joint Stock Company
ICAO	-	International civil aviation organization
EASA	-	European Union Aviation Safety Agency
IATA	-	International air transport association
DTM	-	Digital training model
MES RK	-	Ministry of Education and Science of the Republic of Kazakhstan
DM	-	Digital model
LLP	-	Limited Liability Partnership
FTS	-	Flight Test Station
CLT	-	Computer-based learning technologies
SPT	-	Software pedagogical tool
VR	-	Virtual Reality
HMD	-	A type of computer display device or monitor that, as the name implies, is worn on the head or built as part of a helmet
CAVE	-	An immersive virtual reality environment with projectors pointed at the walls of a cube the size of a room
HTML	-	Standardized hypertext markup language for viewing web pages in a browser
EGNOS	-	European Geostationary Navigation Overlay Service
SIBUR	-	Siberian-Ural Petrochemical Company
ViMeLa	-	Virtual mechatronics lab
VE	-	Interactive virtual environment
VEnvI	-	Virtual Environment Interactions
ASD	-	Autism spectrum disorders
URC	-	Unit repair complex
HRC	-	Helicopter repair complex
A&R RC	-	Aircraft and radioelectronic equipment repair complex
OM	-	Overhaul manual
CP	-	Component Part
TCD	-	Technical Control Department
CRM	-	Control by reference model
DTM	-	Digital terrain model
KB	-	Knowledge base
DB	-	Database
ICCB	-	Input characteristics collection block
IC	-	Input characteristics
PU	-	Processing unit
BOC	-	Block of output characteristics
USDD	-	Unified system of design documentation
GOST	-	Interstate Standard

CL	-	Texturing
LY	-	Layout
DG	-	Digitalization
CAA	-	Civil Aviation Academy
PC	-	Personal Computer
OPSIS	-	Order Preference Technique by Similarity to Ideal Solution
SW	-	Software
GPU	-	Graphics processing unit
UV	-	Transform or unfold in 3D graphics
UE4	-	Unreal Engine 4

1 TASKS OF DIGITALIZATION OF PRODUCTION AND TRAINING OF HELICOPTER REPAIR SPECIALISTS

1.1 Aviation Industry in Kazakhstan

Currently in the Republic of Kazakhstan, air transport is used in almost all strategic sectors of the state: transport, healthcare, defense, national security, prevention and response to natural and man-made emergencies, logistics, etc.

The aviation industry in Kazakhstan includes a number of enterprises, the largest of which are presented below.

JSC National Company Kazakhstan Engineering (Kazakhstan Engineering) [7] specializes in the maintenance and repair of aircrafts and helicopters, development and production of engines for aviation. It was created to improve the management system of the enterprises of the military-industrial complex.

Kazakhstan Aviation Industry LLP. [8] specializes in the manufacture, assembly, repair, maintenance and sale of aviation equipment: aircrafts, components and components for military aircraft construction.

Eurocopter Kazakhstan Engineering LLP [9] is engaged in sales and production of civil and military helicopters, maintenance and repair of H125, H130, EU145, H145 helicopters, as well as training of technicians (mechanics and avionics) and pilots in Russian and English in the CIS and Central Asia.

JSC “Aircraft Repair Plant #406”. [10] is the leading enterprise for repair of light-engine aviation in Kazakhstan, CIS and non-CIS countries.

JSC “Aircraft Repair Plant #405”. [11] is a leading certified and licensed enterprise with a unique repair and technical base in the Central Asian region. The objects of activity are maintenance and repair of aircraft and helicopters, production of components and components for the helicopter industry.

SKY TECH [12] is an aviation technical center for aircraft maintenance, aviation technical support and airworthiness maintenance. It provides supply of spare parts, components and lubricants. Provides services for pilot and technician retraining at the manufacturers’ academies of AIRBUS HELICOPTERS, BELL Helicopter Textron and AGUSTA.

Among the listed organizations of interest is JSC “Aircraft Repair Plant #405” for the following reasons:

– Over the past five years the company has been developing on a large scale, mastering new technological processes, in particular in 2021 there was opened a new production of promising for mountain regions helicopters brand MI8-AMT;

– in its development needs highly qualified specialists, so it actively cooperates with educational institutions, including the JSC “Academy of Civil Aviation”, providing a production base for laboratory and practical exercises;

– actively implements innovative technologies, organizes and participates in scientific research, and is open to the commercialization of promising results;

– there are a number of problematic tasks that cannot be solved without a scientific approach: digitalization of production and technological processes, improvement of training and retraining technologies, increasing productivity, etc.

For these reasons, the direction of dissertation research was related to JSC "Aircraft Repair Plant #405".

Let us consider the production process at this enterprise in more detail.

1.2 Production process of JSC "Aircraft Repair Plant #405

Aviation company has been operating for over 80 years, has a unique technological base and has 39 certificates and licenses for production, maintenance and repair work, accreditation of testing and measurement laboratories.

JSC "Aircraft Repair Plant #405" - leader in the Central Asian region with 40 years of experience in maintenance and repair of helicopters [11]:

MI-8 class: Mi-8PS, Mi-8MTV-1, Mi-8MT (MD), Mi-8T, Mi-8P;

MI-17 class: MI-171-E, MI-17B-5, MI-17-1B, MI-17;

Ka-32A11BC class.

Characteristics of the enterprise:

– The area is 70,000 square meters;

– production area with technological tools, fixtures and equipment - 18,000 square meters.

The infrastructure includes the following production facilities:

– storage rooms for storing products;

– hangar for disassembly of aircraft;

– hangar for assembly work on aircraft;

– aircraft equipment repair complexes;

– hangar for painting work on aircraft;

– The territory of the flight-testing unit with the availability of places for parking and racing helicopters;

– central plant laboratory.

The appearance of the information site is shown in Figure 1.1.

Let us describe the services provided by JSC "Aircraft Repair Plant #405" to the subjects of civil and state aviation.

Engineering - periodic provision of the aircraft airworthiness maintenance plan and information on changes in operational and technical documentation to operators, maintenance of an exchange fund of units and spare parts in the organization's warehouse, and inspections on helicopters.

Figure 1.1 - Information site of JSC “Aircraft Repair Plant #405

Maintenance of helicopter equipment, including periodic, seasonal maintenance for autumn-winter and spring-summer periods, special and during storage.

Modernization - additional equipment of military and civil helicopters according to the developer’s documentation, approved by the Aviation Administration of Kazakhstan.

Extension of operation - organization of research of the technical condition of the helicopter, its units and engines to determine the possibility of increasing their resources and service life.

Repair - processes of overhaul, current and local repair of aircraft engines, units, components and helicopter systems, including the replacement of damaged parts, restoration of the main and tail rotor blades, painting.

Warranty maintenance - repair or replacement of helicopter parts and units that fail within a certain period, troubleshooting services by the company’s operations team, supplying spare parts and components, maintaining a reserve stock of aircraft components and spare parts, providing aircraft components for rent.

Post-warranty service - repair and diagnosis of aircraft and units.

Painting - high quality surface coating of various aircraft and units with certified polyurethane enamels.

Preparation for transportation and loading of Mi-8 and Mi-17 helicopters into the cargo cabin of Il-76 or An-124 aircraft and on the railway transport, transportation of aircraft.

As can be seen from the list provided, the main technological process for the provision of services in the production is the repair of helicopters.

As follows from [13-17], repair of aircraft equipment - a set of methods, methods and means of production, connected by the labor process of specialists for repair, which includes production management, financial activities, provision of energy, supply, as well as the technological process of repair itself.

To the technological process of repair refers that part of the production process, which includes actions to determine the technical condition of the product, the manufacture of new parts, elimination of detected faults, installation and testing of aircraft and their components.

The technological process of aircraft and helicopter repair consists of several major steps:

1) acceptance - transfer of the repaired aircraft or unit by the customer to the repair company;
2) volumetric defect - determining the technical condition of the material part of the repaired object;
3) Dismantling - operations according to the approved lists of works in accordance with technical regulations and documentation;
4) cleaning and washing of units and parts from various deposits that arose during the operation of the aircraft;
5) completing items by group and handing them over for repair;
6) diagnosis with the definition of the technical condition of the repaired object, methods and areas to eliminate detected faults and defects;
7) elimination of detected faults and defects and revision of the design according to the normative and technical documentation for repair;
8) assembly, mounting, testing;
9) transfer of the aircraft to the flight test station (FTS), where the object to be repaired undergoes acceptance testing;
10) ground, flight and other control and acceptance tests;
11) delivery to the customer.

At the enterprise the repair process is carried out qualitatively enough, but there are a number of problems that require urgent resolution with the conduct of scientific research:

– The implementation of digitalization in helicopter repair is required to optimize the technological process, improve workplace safety, form a database of repaired objects and parts to calculate costs and forecast labor and financial resources;

– it is necessary to train and improve the skills of employees using information technology to ensure the quality of the educational process with the assignment of practical competencies at a high level, the minimum financial cost, maximum independent training with minimal disengagement from production instructor-mentors and control the assimilation of training material, considering the risk of action on the repair site;

– creation of scientific-theoretical foundations for modernizing and improving not only repair, but also other production processes.

1.3 Digitalization tools

Digitalization allows to solve a number of production problems [18-20]:

1) Increased data processing speed through the use of high-speed processors and artificial intelligence technologies;

2) Improving the quality of competitiveness of products and services, optimizing production, reducing costs;

3) increasing the staff potential of the enterprise: elimination of “routine” work, optimization of working time, motivation for professional development, mastering of new skills.

In manufacturing, the main tools for digitalization of technological processes are as follows [19-21]:

– Artificial intelligence - a system for coordinating work with remote access, such as a digital assistant;

– machine learning support preventive maintenance, quality control and innovative research, logistics solutions, resource management;

– robotics is introduced into production to imitate human actions or to be effectively incorporated into process lines and complexes;

– cloud technologies enable computing, information exchange with analysis and evaluation of results, and cybersecurity;

– digital platforms and services - bases and virtual platforms for designing the main links of the process chain, processes or elements;

– digital twins - a virtual model for identifying and eliminating potential errors, flaws and risks.

However, the uptake of new technologies is limited. The main factors hindering the implementation of digital tools, and therefore the development of digitalization of production, are as follows:

– high implementation and integration costs;

– lack of resources and competencies;

– the low level of digital literacy and the reluctance of engineering professionals to learn new information technologies;

– complexity of interface customization and training, especially when implementing artificial intelligence systems;

– sufficient integration with existing information and automated resources;

– imperfect and difficult to use methodological support.

Therefore, it is necessary to propose a new technology that promotes the development of digitalization of aircraft repair enterprises and the effective professional development of specialists in production.

1.4 Computer-based learning technologies

Among the many areas of improving the quality of theoretical knowledge and practical competencies, as well as the effectiveness of the educational process at any level, the following two are the main ones [22-23]:

1) providing the learner with advanced and high-quality means to implement their capabilities to acquire the skills of new activities, knowledge and skills;

2) intensification of the learner's mental activity due to optimal distribution of time resources, professional dialogue with the teacher and work in groups.

In these areas, computer technology is the most effective and promising tool in education.

Currently, computer-based learning technologies (CLT) are divided into the following groups:

– Computer learning environment is a software-based pedagogical tool (PPT) for managing the learning processes of the world around us;

– Computer-based learning program - a SPT to achieve didactic goals in training;

– automated learning system - SPT for cognitive management with human-machine complex in the learning process;

– electronic textbook - a set of information pages in electronic format with the inclusion of computer graphics elements;

– expert-learning system - a faculty with some elements of "artificial intelligence": recommendations for mastering the learning material, assessing the level of knowledge and training, taking into account the level of training of the learner;

– authoring tool environment - SPT for the development of software applications and other products;

– controlling program - a faculty for controlling the learning process and organizing feedback;

– computer simulators of technological equipment - SPT with simulation of real processes and situations to consolidate the necessary knowledge and competencies;

– demonstration program - a faculty for visualizing or presenting the world or professional environment.

– service software packages - SPT with the function of professional training.

Based on the above analysis, we can conclude that computer educational technology - a set of models, methods, algorithms, tools and forms of impact on the learner.

According to the functional purpose and application of CLTs are divided into the following groups:

– training - to reinforce skills and competencies;

– Mentoring - with the function of formal dialogue in teaching;

– problem-based learning - with the principles of cognitive psychology, i.e. indirect control of the functions of the learner's activity;

– simulation - with the functions of modeling objects, processes and the environment;

– gaming - with game technology;

– controlling and diagnostic - with the functions of analyzing answers, assessing the level of mastering the material, identifying errors and making adjustments in training.

The above-mentioned CLTs have a number of advantages, which is why they are widely used in the educational process. But they also have a number of disadvantages, including:

– low level of interaction of the learner with the computer;

– does not cover all the functions necessary for complete learning;

– task conditions do not allow you to dive deeply into the task, not sufficiently aware of the result of their actions;

– the teacher (or instructor at the company) effectively and objectively assesses the theoretical knowledge and practical skills in relation to the real object;

– the learner cannot independently form the task and manage the simulation of the experiment, to correct actions in training;

– insufficient consideration is given to the individual characteristics of the learner, including reflexive control.

Teachers and instructors have realized the great importance of computer technology in their professional activities, but there is a systemic problem: unable to link methods of presenting information with the programming of pedagogical tasks, so they create software products with fragmented application in training.

Consequently, there was a need to create a universal CLT, in the form of a faculty capable of effectively addressing the main goal - to improve the quality of theoretical knowledge and practical competencies. Currently, this has become possible through the use of virtual reality technologies.

1.5 Characteristics of the concept of “virtual reality

Virtual reality (VR) has been known for decades, but at the beginning of this century it gained wide acceptance and found a wide range of professional applications [24-26]. The basic concept of VR is the creation of a digital world (or environment) in which the human user is located and can interact with it in real time. Virtual reality differs from other methods of human-computer interaction in that three-dimensional graphics strive for realism, intuitive interaction and immersion of the user in the digital scene. Immersion is the feeling of being in an artificial environment despite being physically present in the real world, achieved mostly through the use of various stereoscopic projection devices such as head-mounted displays (HMDs) or CAVE systems, joined to solutions for tracking users to improve the sense of presence in the virtual world. In recent years, new low-cost devices have entered the market. Computing power is also steadily increasing, enabling more demanding visualizations and real-time simulations. In addition, access to low-cost or free software to create interactive virtual worlds is constantly increasing. Thus, we can say that creating VR solutions is getting easier and easier.

The virtual reality environment can strongly influence user behavior and feelings and can be used to teach knowledge and skills. Today, virtual reality is widely used in engineering education as well as in many other engineering activities, including simulating the operation and assembly of machines, visualizing knowledge, and configuring various products in the automotive industry.

Virtual reality in education has the advantage of lower costs compared to real models and laboratories. However, this technology is still not widely used. The first reason is that the equipment is expensive, although this is changing thanks to cheap virtual reality solutions such as the HTC Vive or Oculus. The second and most important reason is that creating a VR application for engineering education requires, on the one hand, high programming skills and, on the other hand, a lot of specialized engineering knowledge. The development of effective virtual reality learning tools requires time and investment, as well as full cooperation between subject matter experts and software developers.

A major obstacle to the widespread use of VR is that most solutions are "point solutions," created only for the purpose defined in the current context, without regard to any methodology. Because each solution is immediate, time and cost are high, with frequent errors and corrections. What is needed is a methodology that can speed up the development process and produce more efficient results.

1.6 Types of virtual reality

The modern development of virtual reality technologies allows us to classify them according to the following types.

1) Immersive VR technology.

This type provides a simulation of the virtual world with a high degree of detail and plausibility. The implementation of such technologies is carried out with the help of a high-performance computer capable of recognizing the activities of the user of the technology, and responding to actions in real time. The immersive effect is provided by the use of special equipment [27].

2) Immersive VR technology.

Non-immersion technologies provide simulations with image, sound and controllers that are broadcast on a screen, mostly widescreen. Such systems do not fully realize the requirements for VR, but they are far superior to other multimedia tools in terms of the impact on users [27].

3) VR technologies with shared infrastructure.

These technologies are distinguished by such facts: the immersion effect is not inherent; allow interaction with other users. Good examples of Second Life, which is a three-dimensional virtual world with elements of a social network, the game Minecraft and others. Virtual worlds are not only used in the game industry. Platforms such as 3D Immersive Collaboration allow organizing working and learning 3D-spaces, the so-called "collaborative work with the effect of presence. One of the important directions in the development of virtual reality - is to provide full immersion, with the possibility of user interaction [27].

4) Internet-based VR.

First of all in this technology should be called the Virtual Reality Markup Language, similar to HTML. Unfortunately, modern developers rarely use this technology, considering it outdated. However, there is a high probability that in a few years virtual worlds will be created on Internet technologies [27]. This statement is confirmed by Facebook's interest in VR.

1.7 Analysis of VR applications in industry

Here are examples of practical implementation of scenarios for the use of VR abroad and in Kazakhstan. One of Japan's largest air carriers, Japan Airways, together with Toshiba System Technologies Corporation, is developing virtual reality technologies for training maintenance personnel on Embraer E170 and E190 aircrafts. Test runs were conducted from July to early September 2019. The VR program simulates the procedure for starting aircraft engines and accurately simulates various indicators and sounds inside the cockpit. In addition, technicians can use this program to test their knowledge and identify areas of skill that can be improved [28].

The Russian company "Modum Lab" for more than 15 years is engaged in IT-solutions for work optimization, as well as employee training and professional development, including more than 6 years developing virtual and augmented reality VR/AR solutions for large companies such as "Gazprom Neft", "Sberbank", "Biotechnology Company", etc. [29].

The range of applications of VR technology is very wide, especially in the design phase, often used as an extension of CAD systems. In the European automobile concern Volvo, engineers and designers use VR for effective collective communication in studying the ways of layout of the designed vehicle without prior physical prototyping. As a result, the company obtains a significant reduction in the cost of design and engineering [30].

The European aviation consortium EGNOS uses VR to integrate digital mockups into the production environment, thus providing access to a 3D model of the aircraft during production for assemblers. As a result, the time required to control the assembly work is significantly reduced (a reduction from three weeks to three days has been mentioned) [31].

Researchers at AGCO (USA), a large electrical and mechanical engineering concern, use virtual sensors, which are fully functional computer models of real sensors. Virtual sensors are used to study the functioning features of real sensors, provided they can be placed inside the engine. The technology provides an opportunity to observe the exact model of the engine and its internal device with simultaneous overlay of audio explanation of the peculiarities of the simulated equipment operation [32].

At Enel, a major European energy company, personnel are trained using VR helmets to perform procedures and operations to develop skills in equipment maintenance, repair and replacement, increasing efficiency and safety. As a result, the power company has achieved increased productivity and reduced risks to personnel. VR technology and real-world production data are used to quickly and safely inspect operating equipment to reduce the risk of injury to personnel, and to help identify failure or accident locations [33].

Automakers organize virtual meetings to discuss new vehicle designs for designers and planners located in different regions. As a result, there are savings on travel expenses, designers and planners have access to up-to-date information on the project, which naturally leads to faster development.

Russian company Gazprom Neft has been actively exploring the industrial use of VR technology for several years. By the end of 2018, the company had implemented thirty scenarios using VR: a VR training platform was developed; a pilot acceptance of an engineering model in VR; an equipment operation control scenario was performed; automation of warehouse processes was implemented; a scenario to establish the identity of a 3D model of an object under construction with a physical object at the construction site was implemented [33].

At Severstal, VR-technology projects are mainly carried out in terms of training: virtual simulators for training production personnel, practicing the skills of working specialties [33].

At SIBUR, VR technologies are used to improve the quality of maintenance and repair work at plants, implement tools for remote consultation of various specialists (fitters, mechanics), practice actions when working with hazardous reagents, as well as when studying the basics of industrial safety and working in hazardous conditions [33].

Rosneft is experimenting with VR for underground/subsea pipeline construction projects in the Far East. Russian Railways is exploring the possibilities of virtual reality technology in the educational process at professional qualification centers, as well as in the construction of high-speed lines. In the EVRAZ holding company, VR solutions are used to popularize enterprises, attract candidates for employment and for the initial familiarization with working conditions [33].

In Kazakhstan, 10TECH finds solutions mainly in the field of augmented reality (AR) for industrial enterprises: trainings for personnel using simulation models for augmented reality glasses; preliminary modeling of an object under construction in 3D format. However, today there are not many industries in Kazakhstan that actively use advanced technologies [34].

1.8 An overview of examples of the use of virtual reality in education

The term “education” usually refers to the process of facilitating learning, acquiring knowledge, skills, or positive values. The primary purpose of education is to prepare students for life, work, and citizenship by developing their knowledge and skills that are considered necessary in society. It is the educator’s job to enhance the qualifications, competencies, and skills of graduates as they learn. Classes are usually divided into two parts: theoretical and practical, such as exercises, laboratories, or internships [35].

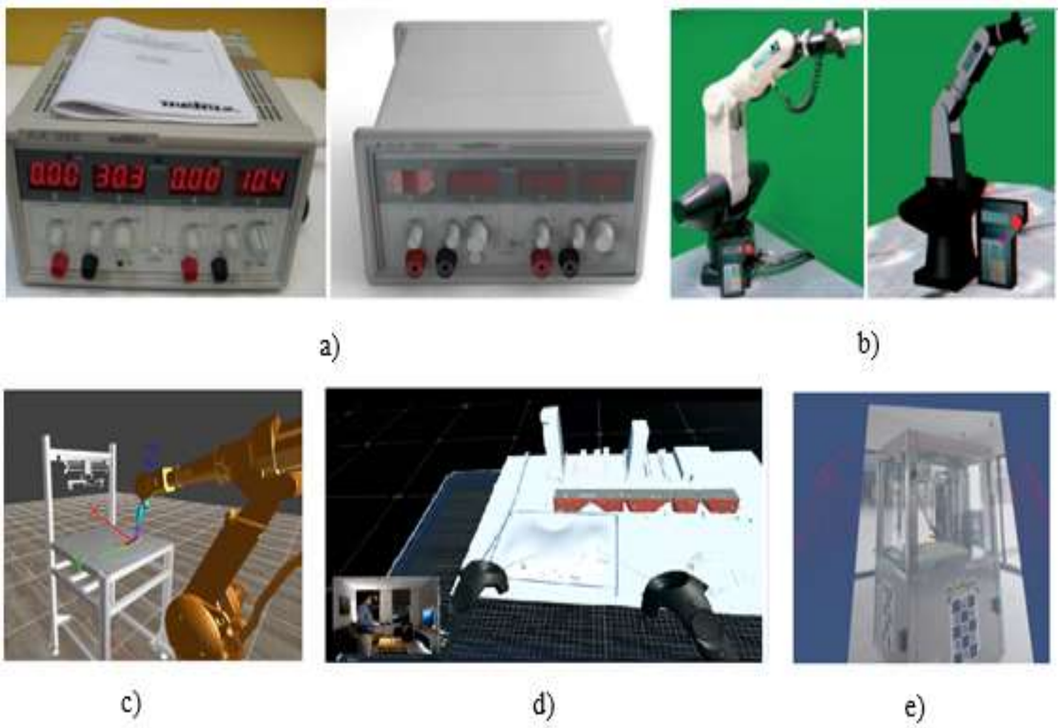
Many students have trouble understanding issues, especially science courses, because of their technical complexity, the need for abstract thinking, and the fact that these concepts are not entirely tangible. Lack of fundamentals hinders further development and exploration of more complex problems. Practical exercises, mostly based on specialized research equipment, must be performed under supervision; consequently, students cannot set up laboratory equipment on their own, experience emergencies or the consequences of misconfiguration that could lead to damage to the equipment. Moreover, there is no opportunity to practice and catch up outside of the lab schedule. Numerous examples of hardware and software that have been successful in educational processes show that the educational technology industry can improve learning outcomes for most students [36].

More and more education centers around the world are beginning to adopt powerful new technological tools to help them meet the needs of diverse student populations. It is well known that the use of information and communication technologies improves student attitudes toward learning [37-39]. Over the past few years virtual reality (VR), which is an interactive computer environment, has moved from the realm of gaming to the field of professional development.

1) Educational VR applications in engineering education.

Virtual environments can be widely used as simulators for engineering training. Virtual reality gives engineers a better understanding of facility design and helps them make changes when necessary. Moreover, it helps reduce the time and cost factor that plagues many modern design processes. Figure 1.2 shows screenshots of selected virtual environments for engineering education.

The authors [40] presented a VR application to promote education in electrical engineering. They designed and developed online labs that students could access remotely using virtual reality. These projects allowed students to use virtual layouts and virtual tools to perform simple electronic lab work. The application created contained realistic prototypes of 3D models of all the equipment, as well as appropriate electrical components for experiments.



a) power unit in reality and virtual;
b) CRS robotic arm in real and virtual;

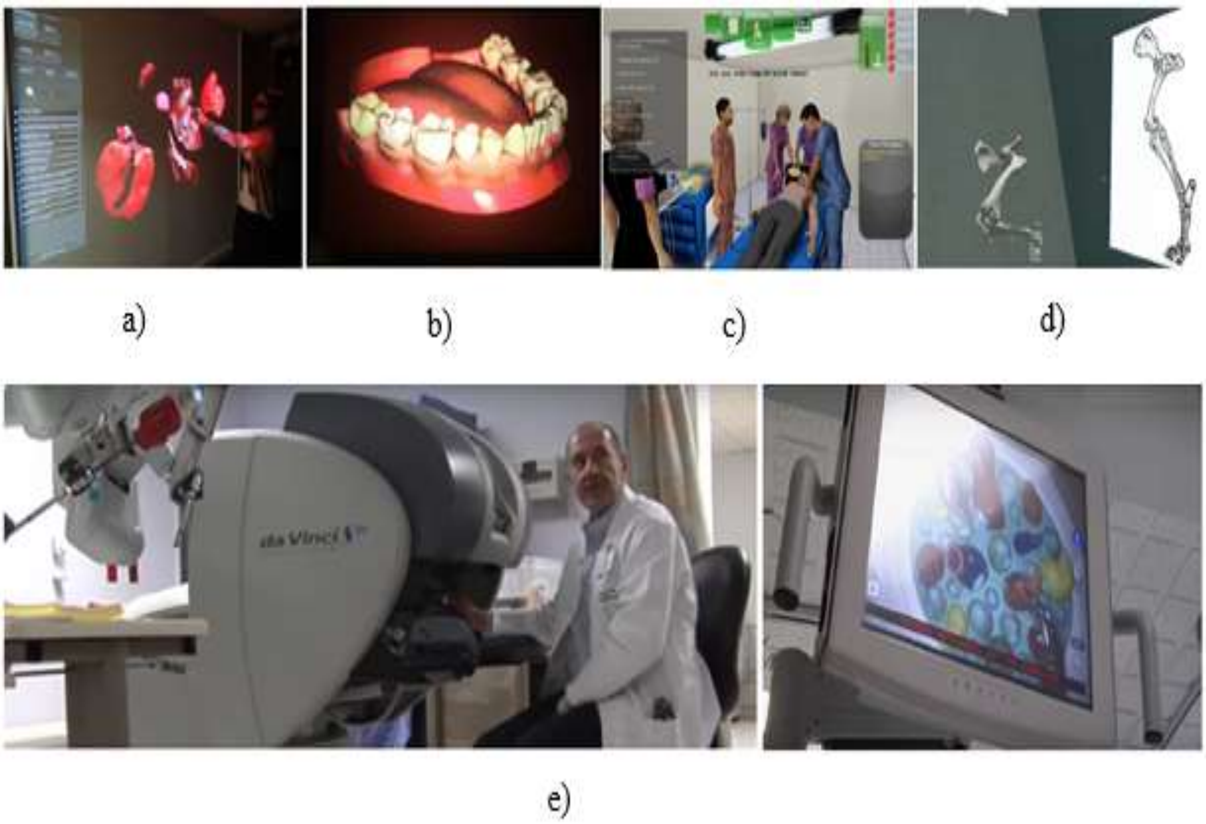
c) robot cell for gluing soles;
d) VR in industrial architecture;
e) industrial robot assembler.

Figure 1.2 - Real engineering labs and their representation in VR

A more interesting approach was presented in [41], where the authors presented the Virtual Mechatronics Laboratory (ViMeLa). The goal of this project was to enrich curricula by introducing a virtual reality-based tool for teaching mechatronics in higher education institutions. ViMeLa provided a virtual reality space where students could experiment with simple equipment that allows them to make mistakes and learn from them without real consequences.

2) Educational VR applications in medical education.

Medical virtual reality is a field with great potential to help doctors, nurses, and students improve medical skills through real-world scenarios that provide hands-on learning. Figure 2 shows screenshots of VR environments in medical education.



a) a system of cardiac anatomy in virtual reality;
b) Dental crown preparation training;
c) training to maintain the vitality of the heart;
d) Anatomy Builder VR;
e) conducting operations with the help of robots.

Figure 2 - Screenshots of virtual reality applications for medical education

In [42], the authors present a VR system that offers a three-dimensional representation of the heart structure in an interactive real-time environment. The application allows some interaction, such as free manipulation, and disassembly of models to represent the true anatomical relationships of the different parts of the heart.

In [43] they present Simodont, a 3D VR simulation system for teaching crown preparations. The simulator can differentiate between dental students and prosthodontists in terms of both time and skill, thus confirming its suitability as a teaching tool.

The purpose of the application shown in [44] is to improve training in surgical hand preparation, which is an important practice in preventing postoperative infection. In addition, the ophthalmic surgical VR magic Eyesi simulator provides a realistic environment for the acquisition of psychomotor skills and the development of microsurgical spatial perception, which can be applied to real cataract and vitreoretinal surgery [35].

3) Educational applications of VR in space technology and mathematics.

Virtual reality presented a new way to teach astronomy and space technology. A new interactive virtual environment (VE) was proposed in [45], which used a dynamic 3D model of the solar system. The student can enter the virtual model of the physical world. Then he/she can zoom in or out and change his/her point of view and perspective, while the created virtual world continues to work in its natural way.

In [46] they proposed a 3D geometric construction tool based on a collaborative augmented reality system.

4) Educational VR applications in general education.

VR can serve as an inexpensive, easy-to-use, user-friendly tool and resource. A great example is Google Expeditions, which allows a teacher to take an entire class on a virtual journey. The app recreates an immersive real-world experience using 360-degree videos shot in different locations, such as an underwater exploration of coral reefs in the South Pacific or the Louvre in Paris using Google Street View technology [35]. VEnvI (Virtual Environment Interactions) [47] is a visual programming tool that combines dance, computational thinking and embodied interaction. Using the Oculus Rift HMD, participants had the opportunity to be present with the virtual character they were programming, get a first-person view of the staged performance, make changes, and correct errors.

The authors [48] presented the use of VR to study geospatial and geological data from the Icelandic volcano Trichnukar, provided a detailed description of this experience and discussed the long-term vision of creating an effective and easy-to-use platform suitable for this. for researchers and teachers who are not experts in virtual reality programming.

5) Educational VR applications in special education.

The literature increasingly recognizes the potential benefits of virtual reality as a tool to support the learning process for unique needs. Many studies point to the critical role of this technology in improving the behavioral, communication, and social skills of children with autism spectrum disorders (ASD) [35]. Recently, virtual reality has been seen as the best method for monitoring an intervention for ASD using everyday human and computer-based virtual reality tasks.

In [49], the authors tested the therapeutic effect of VR physiotherapy on gait balance and the frequency of falls after a stroke. A group of 30 patients took part in clinical trials of rehabilitation using the Nintendo Wii. They use a variety of games such as tennis, hula hooping, soccer and boxing that require balance. Clinical trials prove that interactive games are a useful tool for restoring gait balance in stroke patients, with a reduction in falls.

1.9 Directions for development and implementation of CLT for training of specialists in the aviation industry

First of all, let us consider the definitions of the basic concepts. By learning system using VR, we will mean a hardware and software environment that visualizes the states and processes of functioning of complex systems, aimed at improving the efficiency of learning.

Training software tools using VR technology for the aviation industry can be used to train specialists in the following areas: maintenance; assembly and repair; quality management; logistics.

Virtual training for attendant training can be organized along the following lines:

- entrance to the robotic cells;
- control of different types of robots;
- inverse robot kinematics;
- the study of exact procedures in a virtual environment;
- possible implementation of prototype technologies, for example, creation of flight simulators, demonstration of aerodynamics processes.

Virtual training for installation and repair specialists can be organized in the following areas:

- learning precise procedures in a virtual environment, e.g. assembly and disassembly of units, defects, washing, lubrication, etc;
- research and study of aircraft structures and assemblies, power supply systems and radio electronics, hydraulics, etc.

Virtual training for quality management training can be organized in the following areas:

- virtual training for specialists of technical control departments;
- study of the procedures for final inspection of workplaces;
- the ability to simulate different states of damage to the final product;
- modeling the activities of aviation services to ensure aviation security.

Virtual training for logistics training can be organized in the following areas:

- learning how to navigate properly with a virtual cart;
- Training in the correct actions when loading and unloading materials and cargo;
- simulation of traffic of transport equipment at airports.

With virtual repetitive learning, employee productivity increases quickly, and potential costly problems that could affect production are eliminated.

The management of JSC "Aircraft Repair Plant #405" has identified the need to organize training of employees of various specialties in technological processes of repair of units and products of aircraft equipment with the help of VR technologies. The use of real units in the training process is not economically viable.

The vast majority of aviation device, system and unit test benches currently in use in the Republic of Kazakhstan are outdated, as are the aviation equipment to which they belong. The cost of a training stand that meets modern requirements is equivalent to the cost of a real aviation unit, device or system. The use of three-dimensional models and virtual reality technologies will make it possible to create virtual simulators that meet modern requirements for the training of aviation technical personnel, multiplying them with minimum costs only for virtual reality equipment. Specialties for which it is necessary to develop interactive training programs to support the training process have been identified:

– unit repair mechanic (unit repair complex (URC))
– aircraft repair mechanic (helicopter repair complex (HRC))
– mechanic for repair of aviation devices (complex repair of aviation and radio-electronic equipment (A&R RC))
– Electrical testing and repair mechanic (E&R).

The flow of trainees will depend on the volume of production, and since it increases every year, there is a need to modernize the training process. Every year the plant is mastering overhaul of aircraft components. Training programs will be written for components that are part of the basic equipment of the helicopter, which will not lose its relevance over time. According to the actual data for 2020, 7 (seven) apprentices trained for complexes URC and A&R RC, HRC in the above-mentioned specialties were trained at JSC "Aircraft Repair Plant #405".

The training programs can be used in the annual training process conducted at the beginning of each year to maintain proficiency.

The training process will be more visual and detailed, the training programs will allow you to virtually learn and perform the repair process through VR technology before performing the real repair process of a component aircraft (aircraft).

The introduction of training programs through VR technology will improve the quality and shorten the period of training, which will save money spent on training the student.

Technological processes implemented in VR will be systematized and reflected on the basis of repair technologies and OM (overhaul manual) of CP (component part).

The model of the technological process is presented in Table 1.

Table 1 - Process model

1	Acceptance for repair of CP
2	CP disassembly
3	CP washing
4	CP defect
5	CP repair
6	Assembly and adjustment of the CP

7	CP tests

Note: "Partial disassembly" is allowed when repairing certain units.

A description of the operations of the technological process is presented in Table 2.

Table 2 - Description of operations

1	**Acceptance for repair of CP**
1.1	Check the CP serial number against the passport data.
2	**CP disassembly**
2.1	Disassemble the CP according to the technology
3	**Washing and cleaning of components and parts of the CP**
3.1	Clean and wash the assemblies and parts according to the technology
4	**CP defect**
4.1	Check the parts and units of the CP with visual inspection. Parts with mechanical damage or corrosion should be rejected or repaired.
4.2	Measure certain parts and assemblies of the CP. Reject parts that have wear and tear.
5	**CP repair**
5.1	Repair defective parts
5.2	Replace parts for mandatory replacement and disposable parts
5.3	Replace defective parts
6	**Assembly and adjustment of the CP**
6.1	Assemble and adjust the CP
7	**CP tests**
7.1	Test the CP with the equipment specified in the technology

When carrying out technological processes, be sure to know the number and role of personnel involved in the process: whether one worker performs, or is expected to work in a group (group size), there may be controlling bodies (their functions).

When performing the technological process of repair, the CP is involved:

- disassembly - 1 specialist (locksmith) - supervised by the Master and the TCD Master;

- washing - 1 specialist (washer) - supervised by the Master and the TCD Master;

- defects - 1 specialist (defectologist) - supervised by the Engineer;

- repair - 1 or 2 specialists (fitter/mechanic) - supervised by the Master and the TCD Master;

- assembly - 1 or 2 specialists (fitter/mechanic) - supervised by the Master and the TCD Master;

- testing - 1 or 2 specialists (fitter/mechanic) - supervised by the Master and the TCD Master;

1.10 Development of VR - applications. Classification of VR - application development

The development of any VR application begins with a conceptual stage (identification and justification), which defines the purpose and expectations of the software product. Based on the defined concept, a VR application can be classified. Each level of application has its own set of functions and requirements, such as the required data types, the means of interaction and the expected behavior of the virtual objects presented. These functions correspond to specific software and hardware components of the VR system. Table 3 shows an optimized classification of VR application development.

The practical significance of the presented classification is that based on the table presented, it is possible to determine which classes of components should be included in the VR application. After defining the type of application, its main characteristics and requirements, it is necessary to determine the sources of knowledge and perform a risk analysis.

Effective use of knowledge in the design process requires its appropriate acquisition and proper recording in a knowledge base. The methods of collecting knowledge also depend on the sources, which can be of various numbers and forms (e.g., personal notes, drawings, diagrams). The representation of knowledge refers to its formal recording. The method of representation should be as simple, complete, comprehensible and unambiguous as possible, not only for those engaged in its description, but, above all, for those who will use it.

Table 3 - Classification of VR application development

Requirements	**Degree of implementation**		
	Level 1	**Level 2**	**Level 3**
1	2	3	4
Visualization	Static - pre-rendering	Kinematics - real-time rendering (3D engine, live animation)	Dynamic - real-time rendering with object deformations
Animations	Simple, pretreated	Rigid bodies - in real time, deformations - pre-drawn	Both rigid and deformable bodies in real time
Methods of object manipulation and interaction	Mouse, keyboard, graphical user interface, gestures	Graphical user interface, gestures, tracking	Graphical user interface, gestures, tracking, tactile manipulation with force feedback
Collisions and user feedback	not available	preferably	Be sure to
Tracking accuracy and forces required	low degree of measurement is unnecessary or acceptable	medium or low measurement	high degree of measurement
Required computing power	low or medium	medium or high	high

Conclusions of the first section

The following conclusions can be drawn from the data of the study.

Aviation industry of Kazakhstan includes enterprises that implement a number of important technological processes: production, maintenance and repair of helicopters. However, the most promising and requiring urgent introduction of advanced technologies is JSC "Aircraft Repair Plant #405" for reasons: the transition from repair to production of helicopters, the need for continuous professional development of employees, openness to the introduction of innovative technologies and commercialization of research results.

On the basis of research, it was found that in the technological process for repair of helicopter equipment, including JSC "Aircraft Repair Plant #405" there are a number of problems that require urgent resolution with the conduct of scientific research:

– The introduction of digitalization is required to optimize the production cycle, improve labor safety, create databases of objects and parts, and calculate and forecast resources;

– It is necessary to train and improve the skills of employees using innovative information and communication technologies to ensure the quality of the educational process, with minimum cost and maximum self-training on-the-job;

– create scientific-theoretical foundations for digitalization, modernization and improvement of repair and production processes.

In order to provide the learner with advanced and high-quality tools for the implementation of opportunities for students to gain knowledge, skills and abilities, as well as intensification of mental activity based on the distribution of time resources and professional dialogue, are computer-based learning technologies. The definition of CLTs, their classification depending on the functional purpose in air transport is proposed.

Based on the analysis, it was found that there was a need to create a universal CLT that can more effectively address the main goal associated with the application of virtual reality technology.

The basic concept of VR is to create a digital environment in which the user and can interact in real time. The benefits of virtual reality have been established in the use of near-realistic three-dimensional graphics, intuitive interaction and immersion in a digital environment.

Considered the classification of virtual reality, depending on the degree of immersion and hardware and software.

On the basis of the analysis the results of research on the analysis of application in industry, including in Kazakhstan for training with the use of augmented reality glasses and preliminary simulation of the constructed object in 3D-format. However, currently there are no aviation production facilities in Kazakhstan, using advanced virtual reality technology.

Presents the results of research on the application of virtual reality in the field of education, which allowed to establish the basic requirements for the implementation of digitalization tools and learning helicopter repair processes.

The conceptual apparatus and areas of application of virtual reality in the aviation industry are described. training areas for training installation and repair specialists, the specialties for the application of interactive training programs are determined. The model of the technological process and description of operations of the technological process of repair of helicopter equipment are developed. The stages of development of virtual reality applications were developed.

It was found that the most effective tools for the digitalization of computer-based learning technologies are special structures based on 3D - modeling and VR - virtual reality.

Developed scientific-theoretical provisions allow to improve not only the repair process, but also other technological processes of various industries. Optimize technological processes, improve workplace safety, form a database of repaired units and parts to calculate costs and forecasting of labor and financial resources.

2 DEVELOPMENT OF DIGITAL TRAINING MODELS OF HELICOPTER REPAIR PROCESSES

2.1 Conceptual framework and classification of DTMs

According to the author of the thesis, the concept of "digital model" entered the scientific terminology during the formation in 1961 in the theory of automatic control of a new scientific direction on control with a reference model (CRM) [50-52]. The results of the implementation of the proposed scientific provisions have shown high efficiency when applied in the electric power industry, mechanical engineering and aviation.

The idea of the scientific direction of CRM is based on the cyclic comparison of the impulse characteristics of the reference (ideal) model with the real object or the design, control and management process. As a result of the difference, corrective, or adaptive, influences are formed to improve the efficiency and quality of control, and the systems themselves have been classified as adaptive.

In aviation, the term "digital model" is related to the facts of the introduction of autopilot, when an automated "rudder sense" system was additionally connected to the standard speed control of the aircraft, facilitating the activity of aircraft personnel. In this device, the response of the aircraft to pilot control signals to the servomechanisms is periodically compared with the response of the reference model, which is proposed by the developer, which significantly increases the efficiency of aircraft control.

Further development of the application of digital models is significantly associated with the rapid introduction of automation and digitalization technologies, the definitions of which are also constantly improving. Considering the modern achievements of science, engineering and technology, the following definitions, which most clearly reflect the evolution of the implementation of digital technologies, are proposed.

Automation is the implementation of real processes (technological, social), in electronic format and the replacement of human activities with robotic technologies.

Digitalization is the creation of an electronic duplicate of a real object or process, containing the tactical and technical characteristics of the design elements, the principle of operation, as well as information about the development, design, operation and maintenance.

Consequently, automation and digitalization are based on digital models (DM), which, according to the evolution of their development, the author of the thesis proposes to divide into the following three groups:

- DM-1 of the first kind - a structure representing a real object or process by mathematical and logical dependencies of input and output parameters, geometric or expert description, including research methodology, analysis and output of simulation results in a form convenient for the user.

- DM-2 of the second type - man-machine interface, where DM-1 is implemented with the use of modern computer programs, allowing, changing the input parameters, including in time, to form and present the results of the study in statics and dynamics.

- Third kind of DEM-3 - prototypes of realistic objects or processes, including a set of input parameters in the form of numerical values and computer files, computational methods and tools for mathematical and expert analysis of two-dimensional and three-dimensional data in digital format.

Currently CF-3 are the most promising, as they have found wide application, during their creation the time to develop a technical specification is significantly reduced, modern software and easy to use and maintain computer tools are actively used, and, most importantly, it significantly supports and simplifies many real production processes.

The most widespread CF-3 was in the construction of relief [53-56], called the digital terrain model (DTM), in which the output data are represented by two forms:

− 3D images of the earth's surface based on an array of points with identifiable heights, and height information excluding vegetation, buildings and other objects;

− vector data including regularly spaced points and natural objects (ridges, inflection lines, etc.).

Input data: results of geodetic works and topographic survey analysis, information from photogrammetric processing of images and aerospace monitoring, laser and radar imagery.

In industry, DEM-3 also found wide application, in particular, 3D-models of structural elements and units of aviation equipment are formed. This significantly facilitates development and design processes, modeling, preparation of design and estimate documentation, creation of prototypes, and most importantly, allows to significantly reduce material costs, due to optimization of technological preparation of products and products.

As follows from [53-56], the DM-3 allows production organizations and operating companies to save up to 20% of capital costs.

Along with the above advantages, the DM-3 has a number of disadvantages, and, most importantly, it is impossible to provide functioning of the model in a synchronous rhythm commensurate with the speed of dynamic changes of objects and running processes, i.e. in real time mode. In particular, there is no simulation of interaction with the model, by influencing all five human senses.

Based on the analysis of the presented classification, we can conclude that the digital model in principle is a model of the previous type, which includes actual innovative technologies: hardware, software, mathematical and intellectual.

Achievements of modern technology and computer technology [57-59] allow us to propose the inclusion in the classification group of models a new one - DM-4 of the fourth type, forming realistic objects or processes in which dynamic influences and their reactions are transmitted to a person through his perception organs - sensations: eye - vision, ear - sound, tactile sensations - vibration and others.

Outputs of the DM-4 are software applications, technical documentation, description of development and use.

Input data: computer files in text format, video images, technical documents.

To implement the DM-4, special hardware-software complexes are used, including computer devices and devices for simulation and interaction through the user's five senses with the virtual environment: an object or a process.

The advantages of the DM-4 are as follows:

- assess the state of an object or process in real time using sensors;
- simulate various production situations, including emergencies, to test the equipment in static and dynamic modes under various conditions;
- conducting training or retraining of personnel;
- database formation and portal with DM-4 access with easy search and visualization;
- visualization and correction of work statuses at all stages of the life cycle of objects and processes;
- expert evaluation and corrective action during project implementation at any time and at different stages;
- group and individual training, development and design;
- implementation of DM-4, using the features and advantages, and, most importantly, the technology of design and research of DM-3 and DM-2.

The DM-4 has a wide range of applications: from development projects, technical operation and modernization of equipment and technological industry of machine building, transport and energy sectors to simulation of emergency situations and emergency scenarios. But most importantly, professional training of personnel.

Consequently, based on the proposed criteria of classification of digitalization of technological objects and processes four types of models are distinguished, with the most promising being the fourth type of DM-4, which combines all the properties, advantages and achievements of all previous types of digital models:

$$DM-4 = f\{DM-1, DM-2, DM-3\}. \quad (1)$$

It is proposed to consider the application of DM-4 at civil aviation enterprises, with the main aspect directed to the technological process for repair of helicopters. This is due to the fact that the implementation of developed models and technologies will be carried out at JSC "Aircraft Repair Plant #405" (Almaty), whose main production cycle is based on two technological processes - production of MI-8 AMT helicopters and repair of helicopter equipment of MI category.

Figure 3 shows the structure of application of training digital models DM-4 in the process of repair of helicopters.

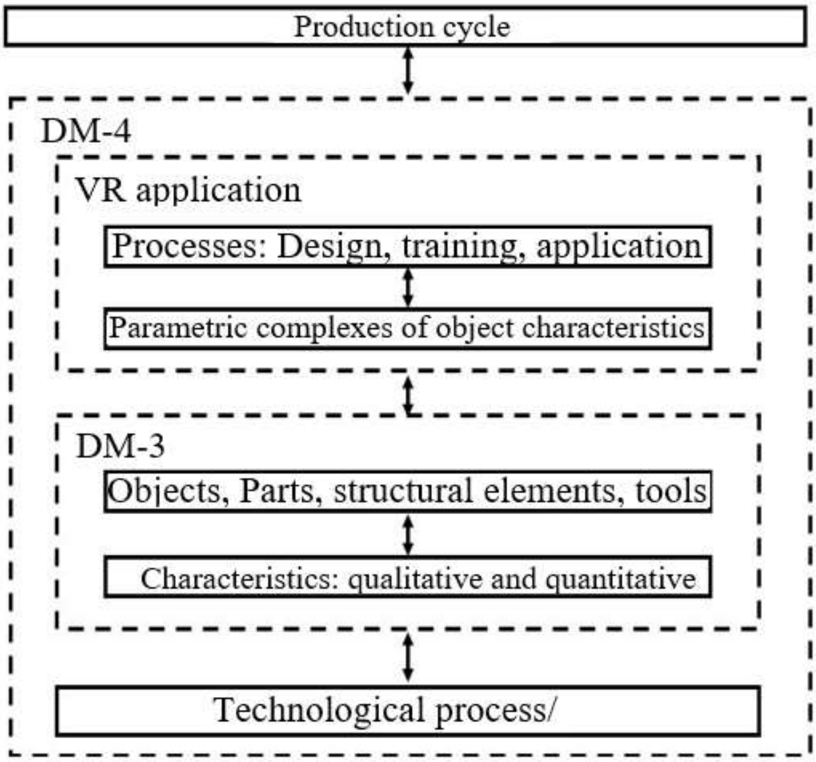


Figure 3 - Structure of DM-4 implementation in helicopter repair process

In Figure 3, the production cycle includes a number of technological processes, including repairs: assembly, disassembly, replacement and defect elimination. DM-4 includes a sequence of computer processing based on virtual reality (VR) technologies of DM-3, which includes objects in digital format and quantitative and qualitative characteristics: geometric dimensions, name of parts and tools.

The developed structure of implementation of DM-4 can find application not only for the helicopter repair process, but also for installation, disassembly, control, diagnostics and management of complex equipment and processes.

Since it is proposed to consider the application of the DM-4 on air transport, and in particular, on the enterprises of civil aviation with the technological process of repair of helicopter equipment, then this type of digital models will belong to the class of “training” for the following reasons:

1) despite the fact that digital models find application in the field of monitoring, diagnostics and management, however, they are widely used for professional training and retraining of technical staff with the assignment of highly qualified practical competencies, which is relevant when commissioning new processes and production facilities, when hiring, when pandemic;

2) digital models are based on the application of artificial intelligence, and, consequently, in its structure the main elements are knowledge bases (KB) and data bases (DB), the main properties of which are *adaptability*, *teachability* and manageability [60-64];

3) DBs continuously maintain records of digital models of parts, inseparable elements, tools and software VR - applications, as well as new processes of input data processing under the control of expert recommendations;

4) in digital models, the input information in them is fully definable, but unmeasurable, with some data are random or contain an element of uncertainty, so the classes are used informational and receptive method of teaching, i.e. accompanied by the use of highly effective informative and multimedia technologies for visual demonstration.

The above-mentioned circumstances refer DM-4 for air transport to the class of digital training models (DTM).

As follows from figure 3, each DTM includes all properties, advantages and achievements of previous types of models. The DTM-4, in order to solve the tasks of implementation in the technological processes of helicopter repair, should have the following types of characteristic support:

− Mathematical - the representation of input and output data, their analysis and processing by the laws of mathematics and logical operations;

− algorithmic - description of digital models functioning in the form of block diagrams and step-by-step sequences;

− Information and production - a set of technical and technological solutions for the effective implementation of digital models in the production cycle;

− Hardware and software - a set of devices, devices, tools and computer programs to implement a digital model, taking into account the requirements of relevance, scientific novelty, high efficiency and practical relevance.

The results of the research presented in the first section show that the use of 3D and VR-based DTM technologies in training has the following advantages:

− the most effective creation of methods of transferring practical skills before working in real conditions, including repair, installation, dismantling, evaluation of activities, management, etc;

− formation of the most real incidents and potential risks, including natural and construction disasters and catastrophes, identification and elimination of defects in important structural elements in air transport;

− quantitative and qualitative assessment of the impact of the number of training sessions on the learning process;

− modeling the elements that aviation professionals will encounter in real life with a representation of the consequences and assessment of man-made and human threats in production;

− creation of an unlimited number of complex scenarios with actions requiring in reality hardware, material and human resources;

− the ability to form professional teams to solve creative and experimental problems in a collaborative and cost-effective way, approaching complex production conditions;

− automated assessment of practical competencies;

− the opportunity to study the material independently, for example, outside of working hours, without distracting the mentors from their main work.

DTM of technological processes of repair of helicopter equipment is a structure that includes complex dynamic and static processes. The peculiarity of the form of representation of the structure shown in Figure 4 is the application of 3D and VR technologies for the development of DTM, artificial intelligence - expert recommendations and regulations for developers and operators.

In particular, mathematical support is needed primarily to represent all the parameters that characterize the functioning of the DTM (input and output data and processes) in a single format, which is necessary for the development of software applications and digitalization of production.

The structure of the DTM, shown in Figure 4, is the basis for the mathematical and logical description of data and processes, as well as technologies for processing and analysis of their quantitative and qualitative characteristics.

Each DTM in the application aspect is individual, because the format of the data and processes must be applicable to computer processing in the knowledge base and convenient for the digitalization of all processes in production.

The acquisition unit (ICCB) shown in the figure 4 is designed for input characteristics (IC) into the DTM. IC - information about the technological process: photos, drawings, videos and technical regulations on the description and repair of units, tools and parts.

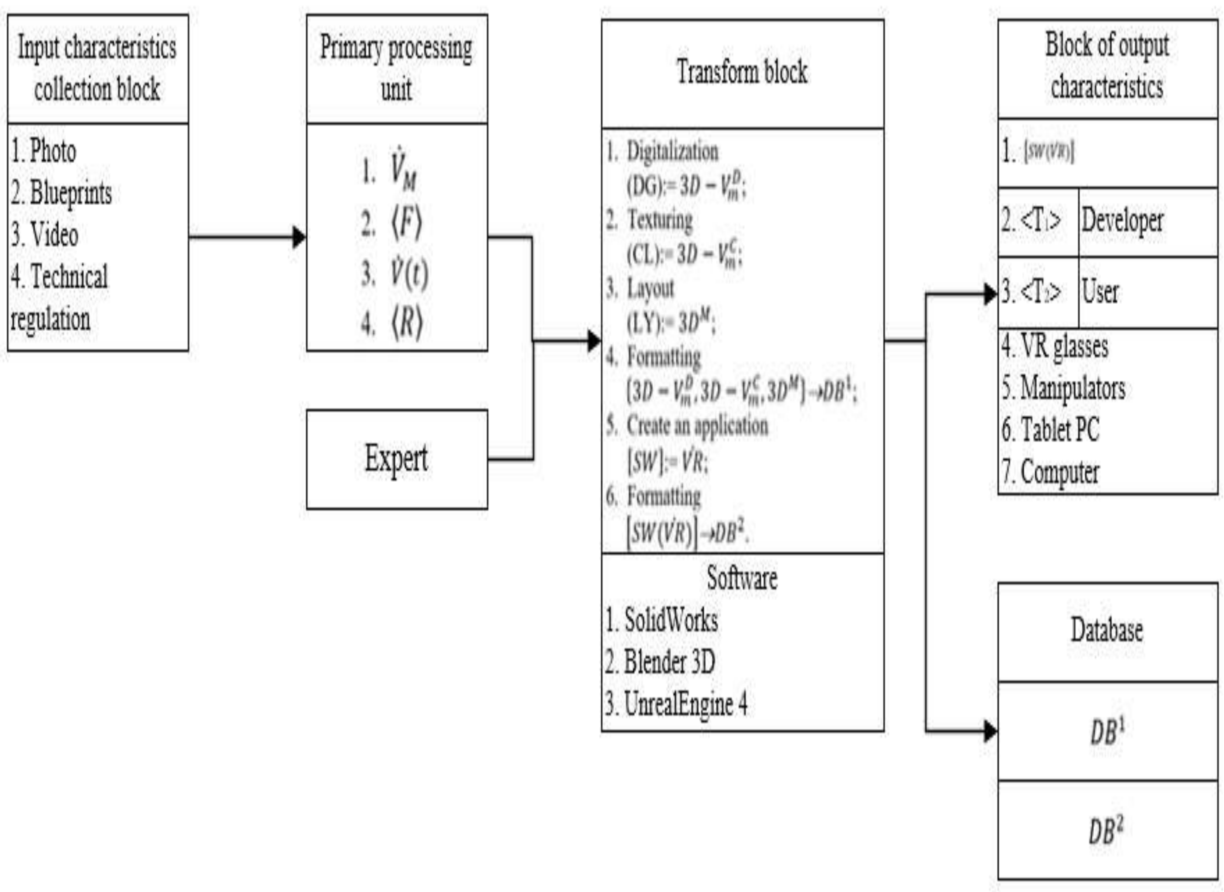


Figure 4 - Structure of the mathematical support of the DTM

Primary processing of IC includes the procedures of their transformation into the functions convenient for mathematical and software processing $\left(\dot{V}_M, \langle F\rangle, \dot{V}(t), \langle R\rangle\right)$ in the corresponding processing unit (PU).

The following processes are implemented in PU: building three-dimensional models (processes: digitization, texturing, layout), in strict accordance with the technological process, creating a virtual reality software application $\dot{VR}$ and conversion into a format for placement in the database.

Almost all processes in PU take place using modern software (SolidWorks, Blender 3d, Unreal Engine 4) and according to expert recommendations of production specialists. All processes will be described in detail in the DTM mathematical software.

After the conversion by means of the block of output characteristics (BOC), the developer is provided with a software application $\left[SW(\dot{VR})\right]$ with the functions of C - control and V - risk assessment, as well as the relevant regulations: $\langle T_1\rangle$ - for the developer and $\langle T_1\rangle$ - for the user.

The database consists of two repositories:

– DB^1 - models of parts, fixed elements, tools;

– DB^2 - Virtual software application recordings $\left[SW(\dot{VR})\right]$.

As follows from Figure 5, the DTM includes the following types of characteristic support:

– scientific-theoretical: mathematical, algorithmic, information-production, hardware-software;

– scientific and applied: risk assessment, programmatic and methodological.

DTM → {
Scientific and theoretical support
1. Mathematical
2. Algorithmic
3. Information and production
4. Hardware and software applied
5. Risk assessment
6. Program scientific and methodological

Figure 5 - Characteristic support of the DTM

Further research is associated with the development of characteristic collaterals of the DTM in accordance with Figure 5.

2.2 Mathematical support for the DTM

Mathematical support for the DTM can be represented in the form of a mathematical model, where the input data of parametric and functional nature at the output is formed $\dot{VR}$-virtual software application in the form of a complex function

$$\dot{VR} = f\left\{\dot{V}_M, \langle F\rangle, \dot{V}(t), \langle R\rangle\right\}. \tag{2}$$

Where:

– $\dot{V}_M$-function for presenting multiple photo images of a prefabricated construction of undismountable parts and tools;

– $\langle F \rangle$ - digital series of graphic images in the form of a functional characteristic;

– $\dot{V}(t)$-*function* to present the video image of the technological process (video film);

– $\langle R \rangle$ - description of technical regulations in the form of a functional characteristic.

The inputs of the DTM are divided into two groups: basic and auxiliary, which are quantitative and qualitative in nature.

Complex function for representing a series of photos of a fixed part:

$$\dot{V}_N = \sum_{k=1}^{N} \left[A_{ij}^k, RGB_{ij}^k, L; \Psi \right], \qquad (3)$$

where A_{ij}^k - is an array element, or a pixel image of a non-detachable part;

ij - the coordinates of the pixels in the photo;

RGB_{ij}^k - color system of pixel unit structure, which by combining red, green and blue colors forms color images;

N- the number of photos sufficient to describe the non-detachable part;

$L_n = x_n + \Delta x, y_n + \Delta y, z_n + \Delta z$ - three-dimensional coordinates of a fixed part with linear geometric dimensions;

$\Psi_n = \alpha_n + \Delta\alpha, \beta_n + \Delta\beta, \gamma_n + \Delta\gamma$- three-dimensional angular coordinates of a fixed part with circular (radial) dimensions.

The rows of photos are systematized according to the expert's opinion and the technical repair regulations, and then the function of presenting multiple photo images of the assembled structure from the rows of undismountable parts and tools, such as a unit or a filter, is formed

$$\dot{V}_M = \sum_{l=1}^{M} \dot{V}_N, \qquad (4)$$

where M- is the number of inseparable parts of the prefabricated structure and tools for their installation.

The second input characteristic is a function of the numerical series, which is formed from the drawings - a set of graphic images made in accordance with the requirements of the USDD and GOST, which are represented by the following mathematical relationship

$$\langle F \rangle = \sum_{l=1}^{M} \left[A_{ij}^Z \right]. \qquad (5)$$

Video image of the technological process is necessary for a strict representation of the orderly sequence of repairs and the formation of rules, is presented in the form of a dynamic structure - a time function in digital format

$$\dot{V}(t) = \cup \dot{V}_M(t) = \cup \sum_{l=1}^{M} \sum_{k=1}^{N} [A_{ij}^k(t), RGB_{ij}^k(t)], \quad (6)$$

where M - is the number of drawings of fixed parts.

$$A_{ij} = \begin{Bmatrix} 1 \\ 0 \end{Bmatrix}. \quad (7)$$

In this case, “0” corresponds to a darkened pixel and “1” to a non-darkened pixel when scanning an object.

The fourth input characteristic is the technical regulation description function, which is formed by pixel transformation by analogy with formula (7) according to the following mathematical dependence

$$\langle R \rangle = \sum_{g=1}^{Q} [A_{ij}^g], \quad (8)$$

where Q - is the number of pages of the technical regulations.

In general, the list of processes is defined by formula (1).

1) Digitalization (DG) - the construction of three-dimensional models of fixed parts according to the requirements of GOST and USCD, according to the expression

$$3D - V_m^D \equiv \{\langle F \rangle_m; \dot{L}_m; \dot{\Psi}_m; DB^1; «E_1»; [SW(3D)]\}, \quad (9)$$

where m - is the serial number of the item;

$\langle F \rangle_m$-drawing, formed in digital format according to formula (5);

$\dot{L}_m$ - set of three-dimensional coordinates of fixed parts with slim geometric dimensions;

$\dot{\Psi}_m$- set of three-dimensional angular coordinates of parts with circular (radial) dimensions;

DB^1 - database of fixed products with geometric dimensions, tools and designs;

«E_1» - expert recommendations of the developer specialist of the enterprise on the formation of figures, lines and entering geometric dimensions with tolerances;

$[SW]$ - designation of SolidWorks software used for mathematical processing and construction of three-dimensional models.

2) Texturing (CL) - giving a color description to non-detachable parts based on real color to visualize technological processes

$$3D - V_m^C \equiv \{\langle 3D - V_m^D \rangle;\ RGB_{xyz}^m; «E_2»;\ [SW(SW)]\}, \qquad (10)$$

where RGB_{xyz}^m - the color system used to form images of three-dimensional models of fixed parts;

«E_2» - developer's expert advice on texturing models;

3) Layout (LY) is the process of assembling a structure of fixed parts according to a technical regulation based on the application of the algorithmic principle of logical comparison of 3-dimensional coordinates with a conditional transition:

IF $(x_m, y_m, z_m) = (x_{m+1}, y_{m+1}, z_{m+1})$
THEN $\langle 3D - V_m^C \rangle \cup \langle 3D - V_{m+1}^C \rangle$
ELSE $m = m + 1$
IF etc.

As a result, a "stitched" three-dimensional 3D construction model is formed using the software $Blenders$

$$3D^M = \{\cup_{m=1}^M 3D - V_m^C, V(\dot{t}), < SW(Blenders) >, \langle R \rangle\}. \qquad (11)$$

4) Entering into the database DB^1 newly developed 3D models of fixed parts, structures and tools

$$\{3D - V_m^D, 3D - V_m^C, 3D^M\} \rightarrow DB^1. \qquad (12)$$

5) Creating $\dot{VR}$ – software application $[SW(\dot{VR})]$providing a virtual reality of the technological process with the help of software$VE4$

$$\dot{VR} = \{3D^M, «E_3»; [SW(VE4)]\}. \qquad (13)$$

where «E_3» - expert advice on layout, placement of elements, aesthetics, and design.

6) Writing to DB^2 - databases of software applications $\dot{VR}$ technological processes of complex designs and objects.

$$\{\dot{VR}\} \rightarrow DB^2 . \qquad (14)$$

Output characteristics ready for use in the aircraft repair process.

$$\dot{VR} = \begin{cases} [SW] \\ \langle T_1 \rangle , \\ \langle T_2 \rangle \end{cases} \qquad (15)$$

where $[SW] = f(C,V)$- is a program module that includes functions:

C - controls and V - grades;

$\langle T_1 \rangle$ - technical documentation (regulations) for the development of $\dot{V}R$;

$\langle T_2 \rangle$- technical documentation for use/operation$\dot{V}R$.

The application of DTM for the repair of helicopter equipment will be quite effective, since the properties of the developed mathematical software satisfy certain requirements:

1) Versatility - a single digital format of data and processes, applicability not only in helicopter repair, but also in other industries;

2) Accuracy - as completely as possible the output dynamic and static characteristics correspond to the properties of the real object: parts, structures, units and tools;

3) adequacy - the total error determined by the errors of measuring instruments and digital conversion processes is 2.5%, while the permissible error is no more than 5%;

4) Cost-effectiveness - the cost of development $\dot{V}R$4) Cost-effectiveness: the development and acquisition of computer equipment and computing resources is 5-10 times lower than the cost of organizing training sessions with experiments on real objects.

Mathematical support for DTM meets other additional requirements: completeness, computability, modularity, robustness, clarity, etc.

There is also observed compliance and the requirement of algorithmization ability - the possibility of creating algorithms and software products for the development and operation of the DTM.

2.3 Algorithmic support of the DTM

There are currently five ways to represent algorithms.

For the development of algorithmic support of the DTM of technological processes of repair of helicopters is used a combined method, including text and graphical representation of the processes of functioning.

In accordance with the structure of the DTM of helicopter repair technological processes, presented in Figure 4, the author of the thesis developed the following textual description of the model functioning algorithm, the output of which is formed $\dot{V}R$ application. Before the development process, it is necessary to study the technological process, set up the appropriate equipment, and the process of installation, disassembly, identification and elimination of defects should be carried out directly on the recommendation of experts - specialists with practical experience.

The design algorithm $\dot{V}R$ application in accordance with the developed DTM in a step-by-step and step-by-step structure is implemented as follows.

Step 1: Input characteristics.

Step 1. Entering photographs of non-detachable parts, sufficient to describe the design, according to formula (3).

Step 2. Systematization of rows of photos of undismountable parts and tools in accordance with the expert's opinion and the technical regulations for assembly/disassembly of undismountable parts, formation of a function to represent the set of photo images of the assembled structure, as specified in formula (4).

Step 3. Entering a set of graphic images - drawings made in accordance with USDD and GOST requirements, their representation as a function of numerical series $\langle F \rangle$ according to formula (5).

Step 4: Input video image V(t) of technological process and representation as a time function in digital format $\dot{V}(t)$ according to formula (6) and pixel preformation according to dependence (7).

Step 5. Enter the technical regulation 〈R〉 volume, representation in the functional dependence by pixel transformation according to the formula (7) and according to the formula (8).

Stage 2: Information processing.

Step 6. Execute the software application development processes, according to data processing formulas (9) - (14):

1) Digitalization (DG);
2) Texturing (CL);
3) Layout (LY);
4) Entering new developed models into the database;
5) Creating $[SW(\dot{V}R)]$The software application of the technological process;
6) Entering into the $DB^2\,\dot{V}R$ software applications of technological processes of complex designs and objects.

The second stage involves the implementation of complex transformations.

Step 3: Output characteristics.

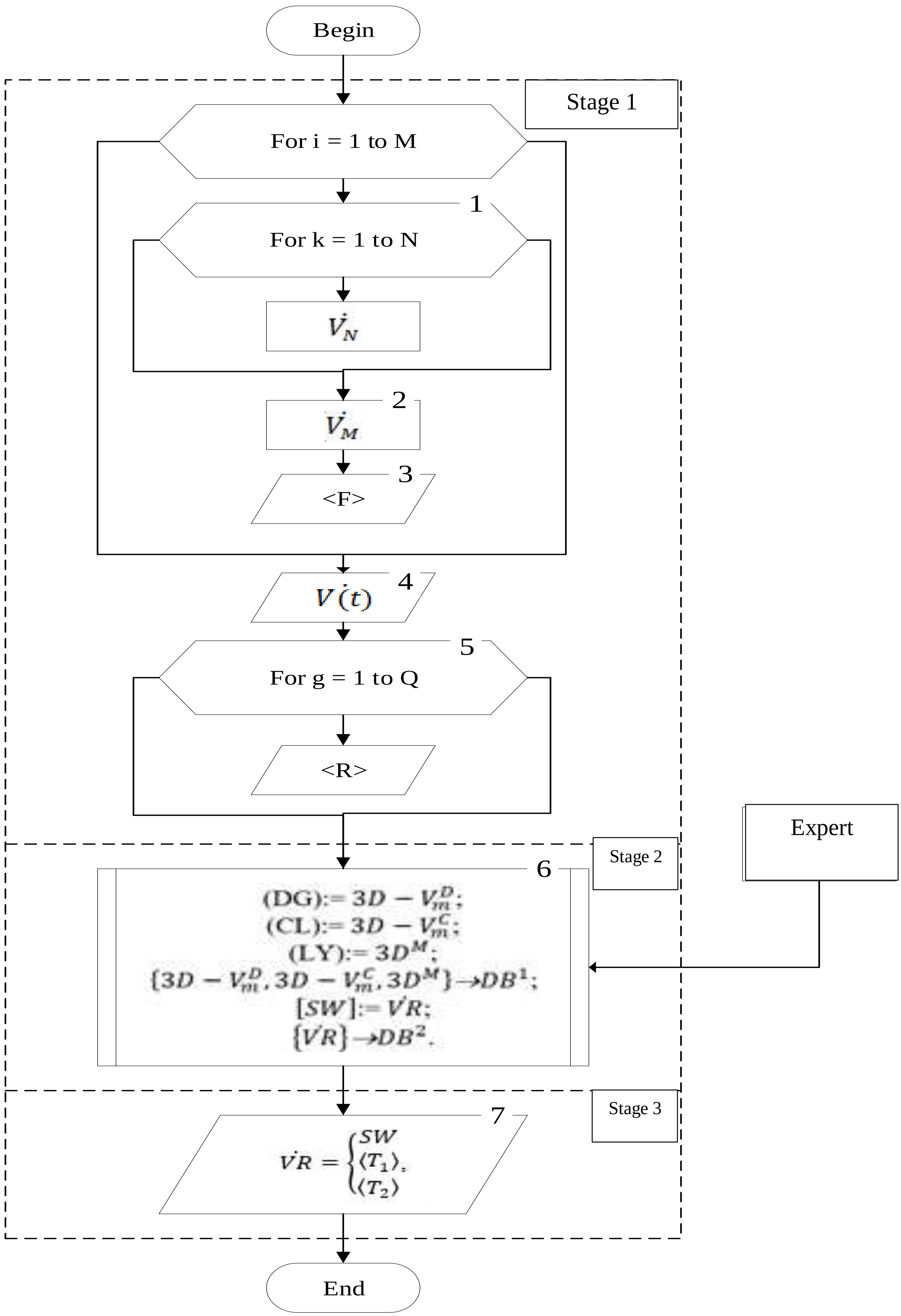


Figure 6 - Block diagram of the algorithmic support of the helicopter repair center

Step 7. $[SW]$ software application of the technological process according to formula (15), as well as - technical documentation for developers and users.

Graphical representation of the algorithmic support of the DTM of technological processes of repair of helicopters in the form of a flowchart is shown in Figure 6.

The conversion operations presented in Step 6 have a complex structure and are presented as a complex data processing procedure.

According to the theory of algorithm development [65-68], the proposed algorithmic software has the following advantageous properties:

− deterministic - for given input characteristics, computational processes offer a single-valued result: the software application $\dot{VR}$;

− performance - after a finite number of steps and steps, the execution of the algorithm must stop and provide the desired result;

− Massiveness - the algorithm is applicable for building a software application $\dot{VR}$ not only in aircraft repair, but also in other industries;

− Discreteness - dissection of the algorithm into specific steps, and the result is not in doubt;

− extremity - each step, step and the whole algorithm is completed in a mandatory manner.

Algorithmic support includes some expert recommendations, but they are necessary to take into account the peculiarities of technological processes. With the constant replenishment of information in databases DB^1 и DB^2 The level of automation will increase significantly.

2.4 Information and production support of the DTM

This type of provision is necessary for the optimal allocation of infocommunication and technological resources of the production cycle. This is necessary to ensure the effective functioning of the DTM, which includes the following results:

1) development of virtual reality software applications $\dot{VR}$, strictly corresponding to the real technological processes and objects;

2) conducting classes for trainees and specialists of enterprises to assign high-quality practical competencies.

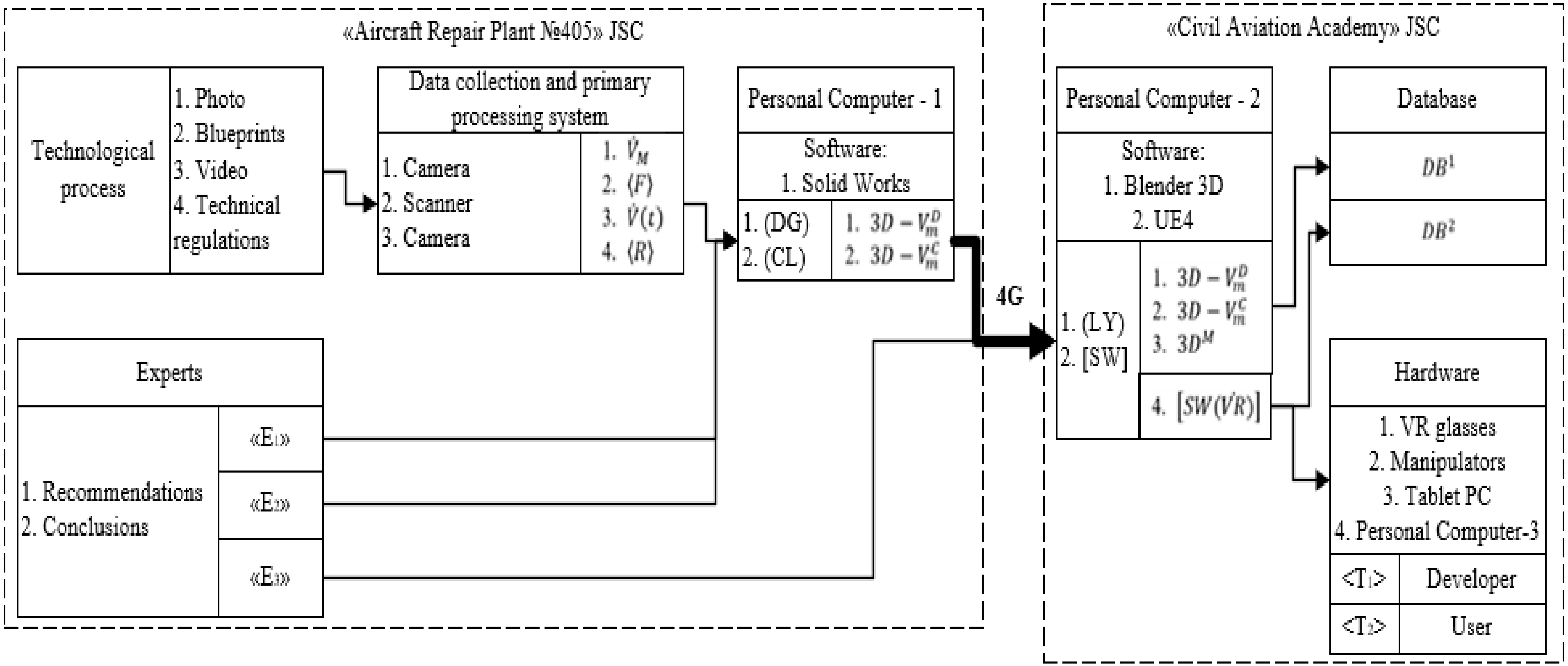


Figure 7 - Structure of information and production support of the DTM

In principle, it is impossible to form a quality training material without the joint work of specialists of industrial and technological enterprises and scientific and educational institutions of civil aviation” (CAA). Both organizations are located in Almaty of the Republic of Kazakhstan.

In the developed information and production support, presented in figure 7, in the first case JSC “Aircraft Repair Plant #405” (ARP) acts, and in the second - JSC “Academy of Civil Aviation”.

Communication between them is provided by means of modern 4G wireless technology, which has the highest technical characteristics by criteria: data transfer rate, coverage area, compatibility with almost all telecommunications devices and computer systems, etc.

The main technological processes of the ARP are the repair and production of helicopter equipment of complex shape. Figure 8 shows the appearance of a prefabricated structure of one unit to be repaired and including more than 50 undismountable parts.

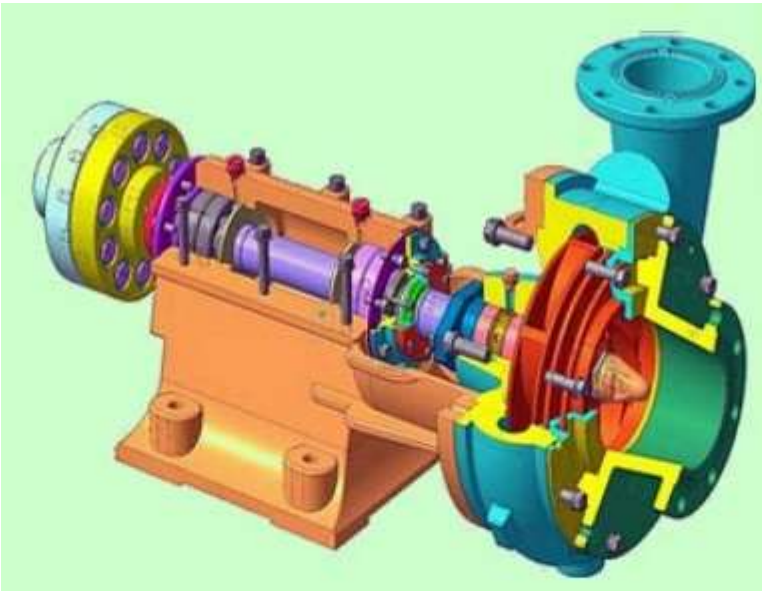


Figure 8 - Appearance of prefabricated unit structure to be repaired and including more than 50 undismountable parts

In order to ensure strict compliance of the developed virtual applications $\dot{V}R$ real technological processes, industry experts are involved as experts to form expert opinions and recommendations (Figure 7):

− strict correspondence of figures, lines and geometric dimensions with tolerances to real objects - «E_1»;

− giving a color description of the non-detachable parts, in accordance with reality, for high-quality visualization of technological processes -«E_2»;

− layout, arrangement of elements, aesthetics, and design of the virtual application «E_3».

The information and production support of the DTM includes a system of collection and primary processing of data that characterize the technological process. In accordance with the mathematical support shown in Figure 4, the input data include photographs of fixed parts, drawings - design documentation, video clips of helicopter repair and technical regulations - an orderly procedure about the technological process in the form of a text file.

The input data are computer files in different formats, directly incompatible with each other. Therefore, it is necessary to systematize them and bring them to a single digital format, presenting them in the form of functional relationships in accordance with the formula (2).

A personal computer with SolidWorks software is placed at the production base, i.e. at the ARP, so that digitalization (DG) and texturing (CL) according to formulas (9) and (10), respectively, are performed, with expert opinions and recommendations«E_1» и «E_2». At the same time, three-dimensional models of fixed parts with a color description are formed at the output.

There is a specialized computer laboratory in which the equipment is installed:

− a personal computer composes (LY) - forms a "stitched" three-dimensional model $3D^M$ structure with the help of software $Blenders$ and software application $[SW(\dot{V}R)]$ virtual reality of the technological process with the help of software $VE4$ with expert advice «E_3»;

− server storage, consisting of two databases DB^1 и $DB^2$and is intended for storing models $3D - V_m^D, 3D - V_m^C, 3D^M$ and software applications $\dot{V}R$;

− specialized equipment: VR glasses, manipulators, tablet and computers with technical documentation for developers < T_1 > and instructors (user) < T_2 >.

In accordance with the theory of system analysis and data processing [69-73], the developed information and production support of the DTM meets the following requirements:

− Completeness - no major revisions will be required after implementation;

− Completeness - the set tasks have a specific result, are feasible and do not contradict each other;

− relevance - implemented in a manufacturing enterprise;

− Feasibility - there is no risk of disruption;

− verifiability - diagnostics and performance testing of the main elements and the system as a whole.

But the main advantage of DTM, according to the evaluation of the proposed information and production software - is the possibility of self-learning, building a database and applicability to other industries and transport.

2.5 Hardware and software of the DTM

This type of support is necessary for the effective construction of the DTM, taking into account the requirements for information and production support. It is based on modern technical means for high-performance implementation, as the structure of the DTM includes the application of technologies in the field of telecommunications, programming, visualization, artificial intelligence, psychology and pedagogy.

2.5.1 Graphical information input device

High performance scanners are used to enter drawings and technical regulations for repairs. The criteria for selecting this device are: resolution, performance, and cost.

These criteria are not correlated, because a scanner with high resolution is expensive. Based on experimental studies, it was found that the resolution equal to 600x600 pixels is necessary for the functioning of the DTM.

The following devices (brand, resolution, performance, interfaces, price) were determined based on the analytical analysis:

- HP Scan Jet Pro 3500, 600x600, 25 lpm, USB 3.0, 169,190 tenge;
- Canon image FORMULA DR-F120, 1200x600, 20 l/min, USB, 142 290 tenge;
- HP Scan Jet Pro 4500, 1200x1200, 30 lpm, USB Fast Ethernet, 370,600 tenge;
- Epson GT-2500N, 1200x1200, 15 l/min, USB Ethernet, 220 800 tenge.

The leading scanner manufacturers are Canon, Epson, HP and others. Below is a comparative table of 1 modern scanners.

For inputting blueprints and technical repair routines, the highest performing scanner is the HP Scan Jet Pro 4500, the appearance of which is shown in Figure 9.

Figure 9 - Exterior view of the HP Scan Jet Pro 4500

2.5.2 Selection of personal computers

There are three types of personal computers (PCs) in the hardware and software of the DTM: stationary, portable and “wearable electronics”. Their use is determined by their location, environmental influences, communication channel and the list of tasks to be solved.

Stationary PC - (Personal Computer - 2), by its purpose must be tied to a specific location, in particular in the CAA laboratory. It is characterized by high performance and speed, because the dimensions allow to place a large number of electronic units. This type of PC, Figure 10, includes the following main elements: processor, RAM, hard drive, motherboard, video card and additional system boards.

Based on the analytical analysis it was found that among the great variety of computer equipment, the most promising for the effective functioning of the DTM is a workstation Dell Precision 5820 is shown in Figure 10.

Figure 10 - Appearance of the Dell Precision 5820 desktop PC

This stationary PC has the following innovative technical and technological solutions:

- Intel Xeon single-processor architecture, up to 18 cores;
- expandable RDIMM memory up to 512 GB and a frequency of 2666 MHz;
- high noise reduction and multi-channel heat extraction system;
- design scaling;
- video cards to work with virtual reality technology and artificial intelligence;
- Up to 6 hot-swappable drives can be installed;
- integration with modern interfaces.

The chosen solution is also effective for processing digital functional dependencies in the form of large arrays of information.

The portable PC (in Figure 11 - Personal Computer- 1) is a laptop. Since its use in the DTM is directly related to the technological process at the ARP, it must be shockproof, dust- and waterproof, and, most importantly, high-performance. The leader among manufacturers of portable PC is also American manufacturer Dell inc. The Dell Latitude 14-7424 laptop, shown in Figure 11, meets the requirements.

Figure 11 - Appearance of the Dell Latitude 14-7424 laptop

This portable PC has the performance of a desktop PC with the following advantages:

- A 4-core 8th generation processor;
- Built-in Intel graphics adapter;
- 14-inch display with anti-glare coating;
- 32 GB of RAM with 2400 MHz;
- 3 slots for hard drives;
- modern network interfaces.

As the third option of PC, is “Wearable Electronics” as a kind of laptops: pocket, tablet (or smartphones). According to the purpose of the PC in the DTM the most effective and promising is a tablet PC with a touch screen to control processes and images with your finger or a special stylus.

With its light weight and support for various types of wireless connections, the tablet PC surpasses laptops in mobility, so it is the most effective equipment for learning with 3D and VR technologies.

Based on the analytical analysis, a tablet PC, also by Dell inc., Latitude 7285, was selected for the work of the DTM, shown in Figure 12.

The main advantageous technical features are:

- size 12 inches;
- screen with a resolution of 2880x1920 pixels;
- X-generation Intel processor;
- rear and front cameras.

Figure 12 - Appearance of the Dell Latitude 7285

2.5.3 Server storage

Server means a hardware and software device for computing and automated systems that performs the function of storing and processing information on user requests for resources or services.

When interacting with the user, some resources are allocated on the server, in our case two databases DB^1 - for storing models $3D - V_m^D, 3D - V_m^C, 3D^M$ и DB^2 - software applications $\dot{V}R$.

The format of server requests and responses are determined by specialized protocols. The server is serviced as a part of the DTM, as well as of the CAA info-communication environment, using various data transmission channels.

Servers are classified into two groups according to their purpose:

- active - operate by collecting data according to predefined algorithms;
- passive - waiting for a request from the user.

For the developed DTM server refers to a passive device and specializes in the storage of complex information and are defined by the following characteristics:

- 99.999% reliability - 24/7 operation thanks to the use of redundant elements: processors, power supplies, hard drives, fan groups, temperature sensors, error correction algorithms;
- sizes from 19” with mounting in standard chassis;
- high-strength housing material with protection against dust, moisture and vibration, and accidental button presses;
- high performance;
- scalability - increasing volume and performance by adding processors or the amount of operating memory to provide high speed processing operations.

Based on the analysis it was found that one of the best manufacturers of server equipment is the company Dell. For the creation of the DTM it is possible to use the server Dell R330-V2, shown in Fig. 13.

Figure 13 - Appearance of the Dell R330-V2 server

The server storage shown in Figure 13 has the following characteristics:

- Intel Xeon E3-1220 v5 quad-core processor clocked at 3 GHz;
- 4 GB of UDIMM RAM at 2133 megahertz;
- 2 SATA hard drives at 7200 rpm;
- RAID controller version S130;
- power supply capacity of 350 watts.

2.5.4 Camera

Modern cameras must produce photographs under any weather conditions at different times of the year with excellent optical performance, without glare or ghosting. That is, for applications in technological processes of any complexity, they must have the following technical solutions:

- high-speed 600 mm / F2.8 lens combined with a 4K shooting mode;
- minimum reflection coefficient;
- high quality images and fast signal processing;
- image stabilization;
- large memory;
- high shooting speed;
- impeccable visibility and framing in direct sunlight;
- macro capabilities up to 1 DM;
- Connecting external memory devices;
- forming systematized rows of photos $\dot{V}_M$.

The above requirements are met by the Panasonic DMC-FZ300EE-K Digital Camera, shown in Figure 14.

Figure 14 - Appearance of the Panasonic DMC-FZ300EE-K Camera

The camera shown in Figure 14 has the following specifications:

- The number of pixels is 12.1 million;
- Sensor - DMOS, cropped (6.2x4.6 mm) 1/2.3”;
- non-replaceable lens;
- weight - 640 grams;
- bracketing.

2.5.5 Video camera

This device with modern technical specifications is compact and mobile, including an electro-optical lens, video signal (digital information flow) shaper, audio signal receiver, video and audio information storage device, memory cards, video monitor.

Camcorders are divided into amateur and professional. The latter have additional functions:

- Time code recording to synchronize image and sound from multiple cameras;
- obtain cinematic quality images in digital standards, including the time function in digital format $\dot{V}(t)$, as described in formula (6).

However, nowadays the “technological distinction” between video cameras is being erased and amateur camcorders can have the above functions, only with less quality features.

Based on the analytical analysis, it was found that the Panasonic AG-DVX200 camcorder is the best solution for this task. Its appearance is shown in Figure 15.

Figure 15 - Appearance of the Panasonic AG-DVX200 camcorder

In the device shown in Figure 15, the distinguishing features are:

- 4/3″ sensor with DCI 4K (4096×2160) recording support;
- Leica Dicomar lens with a focus of 28-365.3 mm;
- high dust and water resistance;
- auto focus.

The listed features indicate the effective applicability of the Panasonic AG-DVX200 camcorder in designing applications $\dot{V}R$ -virtual reality of helicopter repair processes.

2.5.6 VR Headset

Previously mentioned, helmets/glasses are the most popular specialized VR immersion tools. There are the following groups in terms of their connection to electronic devices: PCs, smartphones, game consoles, and standalone helmets.

On the basis of the analysis it was found that for the creation of DTM technological processes of helicopter repair it is most appropriate to use Oculus Quest 2 [74], which works only in virtual and augmented reality. The main advantage is the ability to provide the feeling of a real 3D effect.

The architecture includes the ability to display two video streams on one screen, including connecting two operators with vertical screen separation. Two lenses with different angles present two 2D images as one 3D image.

Oculus Quest 2 requires 60 frames and includes ports:

- HDMI with an alternative DVI adapter to send video to laptops and video cards;
- USB - for data transfer and power to the device.

A 10-foot cable of a certain length is used to eliminate signal interference and distortion.

Oculus Quest 2 features built-in position tracking based on infrared laser LEDs in the headset, which are wirelessly controlled. The built-in two pairs of lenses magnify the screen to fill the field of view, eliminating image blur.

Also included in Oculus Quest 2 are:

− individual motherboard with a Snapdragon XR2 processor and LED control chips;

− “Related Reality Tracker” including magnetometer, gyroscope and accelerometer;

− LED to provide a 360-degree view;

− 5G connection support;

Oculus Quest 2 has a frame refresh rate of 90 Hz, horizontal view of 100 degrees, so there are no empty spaces at the edges of the display, liquid crystal display up to 1832×1920 pixels per eye, The manufacturer added an experimental option to overclock the frame refresh rate to 90 Hz. The amount of RAM up to 6GB.

The helmet includes inertial sensors with six degrees of freedom, two Oculus Touch microcontrollers, and four wide-angle cameras. This provides tracking of the user’s movement and accurately recreates hand positions in VR.

The appearance of Oculus Quest 2 is shown in Figure 16, and its specifications are shown in Table 4.

Figure 16 - Appearance of Oculus Quest 2

Table 4 - Oculus Quest 2 Specifications

Headset	191.5 mm x 102 mm x 142.5 mm (295.5 mm with fully-unfolded strap), 503g; Color: white

Controllers	90 x 120mm (per controller, including tracking ring with IR LED-based tracking), 126g (per controller, without battery), around 147g (with a AA battery); Around 30 hours of usage from one AA battery; Color: white
Display	IPS LCD, 1832x1920px per year resolution, 90Hz native refresh rate (currently capable of 72Hz, 90Hz coming with software update); around 90-degree field of view (estimated); adjustable IPD - three-position slider - 58mm, 63mm and 68mm
Chipset	Qualcomm Snapdragon XR2 (7 nm): Octa-core (1x2.84 GHz Kryo 585 & 3x2.42 GHz Kryo 585 & 4x1.8 GHz Kryo 585); Adreno 650
Memory	64/256GB 6GB LPDDR5 RAM
OS/Software	Oculus Mobile, based on Android 10, no Google Play Services, uses proprietary Oculus store for apps and games; Supports playing PC VR games through Oculus link and thirdparty wireless solutions
Tracking	Supports 6 degrees of freedom (6DoF) head and hand tracking through integrated Oculus Insight technology (inside-out tracking); 4 front-facing cameras for visual controller tracking, plus gyroscopes and accelerometers in headset and controllers; Hand tracking (beta)
Play space	Stationary and room-scale support, up to around 20m x 20m play area is mappable. Headset Battery: 3,640 mAh (14.0 Wh) lithium-ion (2 to 3 hours of use on a single charge); 10W (5V@2A) charging (around 2.5 hours for a full charge)
Audio	Built-in stereo speakers and microphone, 3.5mm audio jack, support for 3D audio
Connectivity	Wi-Fi b/g/n/ac(5)/ax(6), 60 GHz Wi-Fi ay module (currently not in use); Bluetooth 5.0 LE; Type-C USB port, with USB Host support; 3.5mm audio jack

Presented in Figure 16 VR - headset, based on the technical characteristics presented in Table 4, is fully integrated with the selected elements of the hardware and software of the DTM.

2.5.7 Software

At the visualization stage the preparation of 3D and 2D models, export-import procedures, hierarchy and navigation are performed. For this purpose, 3D modeling tools and 2D graphics tools are used. Creating high-quality 3D models of parts for the VR application requires a competent selection of software development environments. The software tools Solid Works [75], Blender3D [76] and Unreal Engine 4 [77] are recommended for use within the proposed methodology.

Solid Works software package: allows you to simulate products of any degree of complexity and purpose. When conducting three-dimensional design and modeling Solid Works in the process uses the Windows interface familiar to many users. All manuals can be presented in Russian in all available versions. The process of building 3D models is based on the creation of elementary geometric primitives and performing various operations on the relationship between them.

The advantages of the Solid Works tool environment:

− production of various 3D models of technological process parts of any complexity and functional purpose;

− no limits on the number of components of complex assemblies and units;

− the ability to prepare accompanying design documentation in accordance with the requirements of the USCD;

− conducting tests under conditions close to real, designed3D-models are tested under conditions close to real;

− multilingual interface, including Russian;

− easy to learn and use with the ability to support multiple standards.

In general, Solid Works is an excellent solution when considering the price-performance ratio but is not devoid of drawbacks - there is an incorrect indication of the size of the object automatically, which you need to correct manually.

Blender3D software is an object-oriented environment for creating three-dimensional computer graphics.

The advantages of Blender3D over programs with similar functionality:

− Free 3D modeling engine with open-source code, which allows you to make changes to the program at your discretion if you have programming skills;

− the small size of the distribution, which is about 50 megabytes;

− integrated six rendering engines, as well as the ability to connect third-party, both paid and free rendering engines;

− the ability to save all textures and resources in a single file;

− many languages, both the interface and the tooltips, which eliminates any problems with understanding the interface.

The only disadvantage of Blender3D is poor documentability, but recently this problem has been solved quite intensively.

The programming phase involves planning actions on objects triggered by certain sensors. The VR programming engine selected in the planning phase is used for the implementation. The programming method depends on the chosen VR engine. To solve the tasks of this stage, the development tool environment Unreal Engine 4 is chosen.

Unreal Engine 4 software is a suite of game development tools with a wide range of features and benefits, including the following:

− the use of the C++ programming language, which is widespread and powerful;

– the ability to create scripts without programming using the Blueprint visual scripting editor.

– a free engine that provides a wide range of tools;

– the ability to create software applications of the highest quality;

– applicability for professionals - VR designers and programmers, and the entire source code is open, and any part can be upgraded to suit the project, which makes the system more flexible;

– After launching the editor, in a few clicks, you can create a project that already has an application template.

The only downside of Unreal Engine is the overpriced content in the store.

The selected software (SolidWorks, Blender3D, Unreal Engine 4) is fully applicable for the implementation of the DTM process of repair of helicopters, which requires computer equipment with the following minimum specifications: Gigabyte G5 GD, Intel TGL i5-11400H, RTX 3050 4Gb, 144Hz IPS, 8x2Gb, M2 512Gb, Win10Home 64.

Conclusions of the second section

This section proposes a new conceptual approach to the classification of digital models and at the conceptual level proposed a new fourth type of model, forming realistic objects or processes based on 3D, VR and artificial intelligence technologies, in which dynamic effects and their reactions are transmitted to humans through their perception organs - sensations.

The structural scheme of training digital models of the DM-4 in the repair of helicopters has been developed.

The scientific-theoretical support of the DTM process of helicopter repair is proposed, which confirms the systematic and methodological approach to the proposed digitalization of production and improving the quality of training with the assignment of practical competencies.

Mathematical support for the DTM is represented in the form of a mathematical model, which from the input data of parametric and functional nature at the output is formed $\dot{VR}$-Virtual software application in the form of a complex function is formed as an output. The effectiveness of the application of DTM for the repair of helicopter equipment is confirmed by the compliance with the requirements: universality, accuracy, adequacy and efficiency, completeness, computability, modularity, robustness, clarity, etc.

Algorithmic support is a step-by-step text and graphic representation of development and functioning of DTM of technological processes of helicopter repair. The peculiarity of this type of software is that it takes into account expert recommendations of industry specialists and replenishment of information in databases DB^1 и DB^2 to increase the level of automation will increase significantly.

Information and production support is intended for the optimal allocation of infocommunication and technological resources of the production cycle to ensure the effective functioning of the DTM. This type of support is proposed by the author and includes the development of software applications of virtual reality $\dot{VR}$ in strict accordance with reality and conducting classes for students and specialists of enterprises to assign high-quality practical competencies. Thanks to this provision, the advantages of the DTM clearly stand out: self-learning, database build-up, and, most importantly, applicability in other industries and transport.

The hardware and software of the DTM is based on the requirements of the previous ones, and it is based on modern technical means for high-performance and high-efficiency implementation and operation. The structure of the DTM includes the application of technologies in the field of radioelectronics and telecommunications, programming, visualization, artificial intelligence, psychology and pedagogy. All of the hardware elements selected as a result of the critical analysis are fully integrated with each other.

The selected software (SolidWorks, Blender3D, Unreal Engine 4) is fully applicable for the implementation of the DTM process of helicopter repair.

Described in this section of the provision of DTM are not complete to describe the DTM, requires the development of new - risk assessment and software and methodological nature, which will be discussed in the next section.

3 RISK ASSESSMENT OF ACTIONS TO BE TAKEN AT THE REPAIR SITE

As follows from section 2, the DTM of helicopter repair processes is a complex structure, but to support the process of training of specialists in aircraft maintenance, or performing technical actions on repair of aircraft equipment is necessary to assess (*V)* performed tasks with the adoption of corrective decisions on subsequent actions.

Combining the DTM with the risk assessment module allows for a causal sequence with assessment in training, which will improve the quality and effectiveness of the educational process, especially in cases of danger.

To implement this task, it is necessary to develop an appropriate calculation methodology, using modern methods and simulation tools for creating scenarios, and hardware technology for the formation of different variants of exercises in VR virtual reality, applicable to technological processes of repair of helicopter equipment.

3.1 Quantitative and Qualitative Characteristics of the Method

The basis for the development of the method was International Standard ISO 31000 “Risk Management - Guidance”. [78], according to which: “Risk is identified as the search, diagnosis and description of critical situations. It is characterized by source, incident, factors, causes and consequences” [78].

Identification is based on scientific-theoretical information and expert opinions. When analyzing risks, criteria are applied, summarized in a reference system, which is a risk assessment. The criteria are defined by requirements, acts, regulations and other dependencies.

Risk decisions are based on safe assumptions, risky behaviors, and following safety rules. Comprehensively, this is called the decision-making process.

In the case of air transport, the consequences of decision-making by aircraft maintenance professionals can reduce or increase the risk leading to accidents, injuries, and incidents [78].

In accordance with the recommendations of ISO 31000 risks must be managed, and therefore, after the identification a specialized risk diagram and flowchart of the management process is developed.

The author of the thesis, taking into account the complexities and peculiarities of the technological process of repair, has developed a flowchart of the control process in the action of aircraft maintenance specialists at the place of repair (Figure 17).

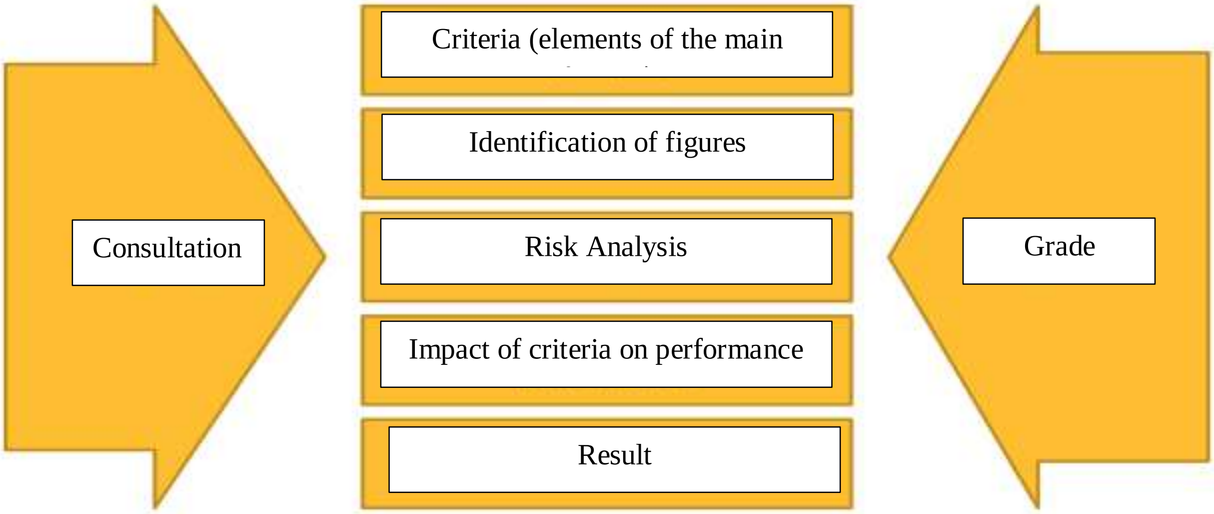


Figure 17 - Block diagram of the risk management process

Based on the flowchart of the risk management process shown in Figure 17, a risk matrix was developed in accordance with the recommendations of the General Director of JSC "Aircraft Repair Plant #405".

The risk matrix model focuses on quantitative and qualitative characteristics:

– level of scenario complexity (*N*) - related to the way each action is performed, depends on the conditions of performance, quantity, and takes into account changes in the intensity of factors;

– decision-making by priority (*P*) - evaluation with respect to the implemented actions taking into account the priority, i.e. in accordance with the sequence of implementations in the context of "changes" in the factors (number, intensity) introduced during the simulation.

– the instructor must strictly determine the sequence of factors and the level of their impact, as well as receive information from the system about the complexity of the scenario.

Mathematically, a matrix is the Cartesian product of two sets, in particular *P* and *N*. Graphically, it is a square with 25 colored cells (5×5).

In the developed algorithm for training in VR - virtual reality, the risk matrix is a key calculation factor, as it allows the instructor to assess the practical competence of the trainee.

The *N* and *P* ratings are presented in Table 5, where the 5 levels are described by percentage ranges (quantitative characteristic) and definitions (qualitative characteristic):

– (0÷20), % - insignificant;
– (21÷40), % - small;
– (41÷60), % - moderate;
– (61÷80), % - serious;
– (81÷100), % - catastrophic.

For a qualitative risk assessment, a graphical form is also adopted when Table

5 is graphically transformed into a matrix of risks of actions of an aircraft maintenance technician performing actions at an aircraft repair site, then the assessment must be “plotted” (Table 6) at the intersection of the two values. On this basis, it is possible to classify and evaluate the level of risk and, therefore, the skills of the student.

- Green - low level;
- Yellow - medium level;
- Orange - high level;
- Red - extreme level;

Table 5 - Rating *N* and *P*

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

Table 6 - Risk Matrix of Aircraft Maintenance Specialist Actions

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

Table 5 and Table 6 assume the following circumstances:

- *P=0%* - the situation when the technical learner performs all tasks in the correct sequence;
- *P=100%* - the case in which the tasks were not completed or the trainee did not exceed the “assessment bar” or the boundary conditions set by the instructor;
- *N=0%* - refers to the beginning of the simulation, t=0.00 sec;
- subsequent value up to N=20% is the least complicated scenario;
- *N=100%* is the most complex scenario.

A two-dimensional risk matrix is the most effective way to determine the hazards associated with repair and maintenance.

Currently, there are other solutions, such as the “Order Preference Technique by Similarity to Ideal Solution” (OPTSIS), in which the alternative is the shortest Euclidean path to the ideal solution [79-81]. However, this method is only applicable in the case of symmetric matrices of dimension X×X, so it is not applicable because in the presented scenario the problems are nonlinear due to different levels of significance.

To develop a risk assessment algorithm, it is proposed to use the “Singapore method/model”, in which the levels of risk present in the scenario and the correctness of tasks are multiplied. Currently, this technology is actively implemented in expert and evaluation applications [82-84].

The model risk assessment method takes into account all factors that affect the quality of modeling, scenario creation and visualization: circumstances, status, actions, inactions, external and internal events, and other conditions that may or may not affect the risk of errors.

Factors affecting the scenario are rated on a three-point scale:

- 1 - medium difficulty in learning;
- 2 - medium difficulty;
- 3 - extreme difficulty.

The categories of the main factors include: infrastructure, conditions, number of aircraft parts, helicopter equipment units, tools for aircraft parts and others. Additionally, dynamic changes of some factors are taken into account, e.g. fogging (from 0% to 100% - high level).

The main group of factors includes a subset consisting of a sufficient list of elements, e.g., a helicopter unit includes right or left-hand threads, bolt tightening forces, etc.

Factors are evaluated by points (weights), which increases the complexity of the simulation complexity (scenario) and ultimately affects the final evaluation of the entire training. The sum of the individual weights equals 1 (100%).

In the assessment method the developed tasks and exercises are coordinated with the technological process of JSC “Aircraft Repair Plant #405”, which should be performed by the aircraft maintenance trainee. Advantages of the method:

- Checking the correctness of the assignment;
- check the sequence of assembly and disassembly of structural parts;
- the ability to create simulations using tools.

It may be noted that work and events with tools for aeronautical engineering is the first approach to assigning practical competencies in the training process.

The classification of tools for air transport repair depending on the purpose is presented in Table 7 and is divided into the following groups:

Table 7 - Classification of tools by purpose

Type of kit	Set number	Set Purpose
EF-1	1	For a technician (flight engineer, flight technician, chief technician-mechanic) of the aircraft
EI-2	2	For the aircraft (helicopter) and power plant (airframe and fuel systems, landing gear and hydraulic systems, control systems, domestic equipment, special equipment, emergency escape equipment)
	3	For electrical equipment and electronic automation
	4	For instrument and photo equipment
	5	For oxygen equipment
	6	For radio electronic equipment
	7	For aviation weapons
	8	For maintenance of the sighting and navigation complex
	9	For operational and intermediate airfields
	10	For mechanical locksmith work
EI-3	11	For aircraft (helicopter) and power plant (airframe and fuel systems, landing gear and hydraulic systems, control systems, domestic 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 data acquisition and processing systems
	18	For the means of emergency escape of the aircraft
	19	For work on the sighting and navigation system
	20	For mechanical locksmith work

EI-1 - for maintenance of air transport by technical aviation personnel;

EI-2 - for maintenance of air transport by engineering and technical personnel of squadrons or aircraft maintenance bases;

EI-3 - for scheduled maintenance and repair of aircraft by the technical and operational unit of the regiment, military aviation repair shop or a separately based air squadron.

The classification presented in Table 3 is conditional, because, for example, for complex repairs the tool set EI-1 may include tool sets EI-2.

For training, these toolkits are defined on a 3-level usage scale:

- 1 - low;
- 2 - medium;
- 3 - high.

The action during training, as well as at the place of repair of aeronautical equipment with tools, is important because it is related to “life-threatening”, so it is reflected in the simulation. The trainee must strictly observe health and safety measures, considering the approach to aircraft parts, trying to identify the type of unit, etc.

The degree of risk from learner error takes only two values:

- 0 - the situation in which the condition of passengers and aviation personnel on board is endangered, and the simulation stops;
- 100 is the state when there is no risk to life and health and it is possible to continue modeling.

In the case of several units in repair, i.e. in complex repairs under different conditions, procedures based on partitioning or sorting into groups are applied:

- red signal - repair of the unit is required;
- green signal-unit is in working condition;
- yellow signal-diagnostics and monitoring of the unit;
- black signal-aggregate is not restored.

In this case, i.e. in the scenario during training on a group of aeronautical equipment units, the order of colors should be evaluated: red, yellow and green. The appropriate weight is also assigned to evaluate the correctness of the trainees' actions:

- red - 3;
- green - 2;
- yellow, black - 1.

3.2 Mathematical model of the method

Risk assessment of trainees' actions on technical repair and maintenance of aviation equipment is based on the mathematical apparatus, which should be implemented in the training VR-technology, i.e. virtual reality.

The error of the specialist's actions at the aircraft repair site is calculated as the instantaneous value for a given moment of simulation, *t*. This makes it possible to identify the most problematic elements for the trainees already in the process of training.

An equation describing the final risk is shown below:

The final risk consists of the risk of action of the specialist is defined by the following expression

$$R_k = K_1 R + K_2 O_I, \qquad (16)$$

where R_k- is the final risk of the specialist's actions at the aircraft repair site,

O_I- instructor evaluation,

R- risk of aviation specialist's actions at the aircraft repair site;

$K_1 = 0{,}4$ or 40% of the final risk estimate obtained experimentally;

$K_2 = 0{,}6$ or 60% - of the final risk score, refers to the instructor's assessment.

Values K_1 и K_2 are determined by the fact that the instructor decides on the satisfactory completion of the training presented, and only the instructor can evaluate non-standard tasks, such as the instructor-trainee interview.

In equation (16) *the R-parameter* is defined as follows

$$R = PN, \tag{17}$$

P- the likelihood of taking rational actions;

N- the level of complexity of the scenario.

The risk of aviation specialist's actions at the aircraft repair site (R) includes the probability of committing rational actions during virtual reality training and the level of difficulty of the scenario created by the instructor.

The level of complexity of the scenario is made up of the main factors that are selected based on the experience of the aircraft maintenance staff. This is necessary to include elements that influence the learning process in virtual reality.

In mathematical terms, this is the product of a given factor and the expert weight assigned to it. For the repair and maintenance of aviation equipment, seven main factors were selected in accordance with Table 8, which consist of elements with appropriate expert weights.

The formula for determining the level of complexity of scenario *N* is as follows

$$N = \big(0{,}1(X_D + X_W + X_I) + 0{,}15(Y_L + Y_O) + 0{,}2(X_T + Y_A)\big)100\%, \tag{18}$$

where X_D is the "infrastructure" factor;

X_W - the "conditions" factor;

Y_L - factor "number of aircraft parts";

Y_O - factor "helicopter units";

Y_a -tools for aircraft parts;

Y_T is the "bolt tightening force" factor;

X_I is the "other" factor.

Table 8 presents the main factors.

Table 8 - Main factors and their weights.

Name	Factor Symbol	Mass
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 tightening forces	T	0.2

Name	Factor Symbol	Mass
Other	I	0.1

Training is carried out according to different variants of scenarios. The main factors and elements are specific and differentiated "parameters", so let's divide them into the following groups:

- Group I - infrastructure, conditions and other things;
- Group II - bolt tightening forces;
- Group III - number of aviation equipment parts, helicopter equipment units and tools for aviation equipment parts.

The difference between the groups characterizes the calculation method for assessing risk.

Group I is determined based on the following equation:

$$X_i = \frac{\sum_{i=1}^{n} x_i}{3n}, \quad (19)$$

where X_i - is the value depending on this factor;
x_i - individual weights of elements of the factor and $x_i \in \{1,2,3\}$;
n is the number of elements of the factor.

Group II is characterized by the equation:

$$Y_i = 0,3\frac{\sum_{i=1}^{n} y_i}{3n} + 0,7\left(1 - \frac{1}{n^2}\right), \quad (20)$$

where Y_i- is the value depending on this factor;
y_i- individual weights of elements of the factor and $y_i \in \{1,2,3\}$;
n is the number of elements of the factor.

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

$$Y_i = 0,3\frac{\sum_{i=1}^{n} y_i}{3n} + 0,7\left(1 - \frac{1}{n}\right), \quad (21)$$

where Y_i- is the value depending on this factor;
y_i - individual weights of the elements of the factor and $y_i \in \{1,2,3\}$;
n is the number of elements of the factor.

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 pieces of equipment. This issue must also be considered in the algorithm. Formula (22) takes into account the weight of the condition element and the level of complexity of the material

$$Y_i = \frac{\sum_{i=1}^{n} a_i}{3n} S, \qquad (22)$$

where Y_i- is a value depending on the work with tools for aviation technology;

a_i- individual weights of elements of the factor (depending on conditions) and $a_i \in \{1,2,3\}$;

n is the number of elements of the factor;

S-dimensionality of this factor in working with tools for aeronautical engineering.

The issue of life-threatening hazards in air transport is directly related to the issue of proper repair of aviation equipment. In carrying out their tasks, trainees and aircraft maintenance technicians of specialized courses must comply with certain safety standards, although it may happen that they find themselves in a hazardous area. This situation should also be included in the simulation. The degree of danger to human life is described by the following equation:

$$L = (1 - \frac{l}{100}), \qquad (23)$$

where L- is the degree of danger to human life (0 or 1);

l- value 0 or 100, where the first value refers to a situation in which a gross error has occurred and human life is in danger. A value of 100 means that there is no danger to human life or health.

The second component of the algorithm refers to the rational action evaluation P_1 , which consists of the task performance evaluation O_z and the task performance evaluation with proper priority O_P . In addition, the evaluation of a rational action includes two important points. The first is task completion and the second is task sequencing. Both problems have the same level of importance. The calculation is based on the following formula:

$$P_1 = \sqrt[10]{\frac{O_Z^{10} + O_P^{10}}{2}}. \qquad (24)$$

Parameters O_Zи$O_P$present in formula (24) are described in equations (25) and (26).

The task assessment O_Z covers the number of tasks performed by the trainee and the total number of tasks in the scenario to be performed, determined by the expression

$$O_Z = 1 - \frac{\sum_{i=1}^{n} C_i}{c}, \qquad (25)$$

where C_i- the tasks performed by the aviation specialist,

c- the total number of tasks in the scenario during VR modeling.

Evaluating a task with the proper priority refers to the sequence of operations with assigned priorities that a technician must perform. There are tasks with the same priority, for example, tasks 1 to 5 have priority 1, and tasks 6 to 10 have priority 2. In this case, the first five tasks in any sequence are performed first, followed by the next five.

This property allows you to create groups of tasks with the same level of importance, and the score O_P is calculated on the following formula

$$O_P = 1 - \frac{\sum_{i=1}^{n} G_i}{g}, \tag{26}$$

where G_i- the number of tasks completed in the correct sequence by the student, g- the total number of tasks in the scenario.

The probability of rational action takes into account the degree of danger to human life L, determined by the formula (23), and an estimate of rational action P_1 in accordance with dependence (24) by mathematical dependence:

$$P = \sqrt[10]{\frac{L^{10}+P_1^{10}}{2}}. \tag{27}$$

Based on the results obtained P and the level of complexity of the scenario N, you can get the data to determine the level of risk based on the risk matrix described in Table 5 and Table 6.

The mathematical algorithm for assessing the risk of aircraft maintenance specialists in virtual reality training simulations is shown in Figure 18 [84-85].

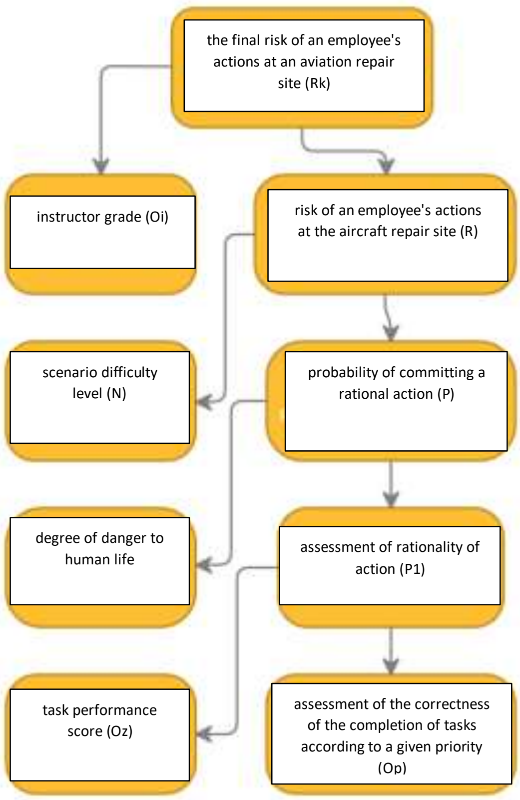


Figure 18 - Block diagram of the algorithm for calculating the risk assessment of actions taken at the site of repair of aviation equipment

The algorithm shown in Figure 18, according to the theory of algorithm development, has all the advantages mentioned in Section 2: determinacy, efficiency, mass, discreteness and finiteness.

3.3 Testing the algorithm

Experimental studies have been conducted to test the method and algorithm for calculating the risk assessment of actions taken at the site of aircraft repair. Test scenarios assume the following variations:

- changes in the level of difficulty;
- The introduction of an incorrectly performed task;
- incompatibility with priorities;
- lack of consistency.

A variety of scenarios allows you to define a wider range of functionality of the algorithm, as well as determine the degree of influence of individual components on the complex course of learning.

Based on the results of the experiment, a set of graphs of the dependencies of the probability of a rational action and time were plotted. Then, based on the risk matrix, the level of risk was estimated, reflecting the skills of the trainee.

Tables 9-11 provide an overview of the three test scenarios and results.

Table 9-Conditions for the organization of test examinations for Scenario 1

Key indicators	**Elements**
Infrastructure	Audience
	Lab
Terms	Without a teacher
	No time
Other	Summer time
	Daytime
	Instructions - present
	Joystick intensity - medium
Aircraft parts	Assembly
	Disassembly

Key indicators	Elements
Helicopter units	Valve H-5810-270
	Check valve 636100
Classes	Class 1
	Class 2
	Class 3
	Class 4

According to the results of experiments and calculations, the difficulty level of Scenario #1 was 63%, which corresponds to the value 4 of Table 5. During the training, the trainee was required to perform 25 actions on the spot in the correct sequence. The achieved result 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, as shown in Figure 19.

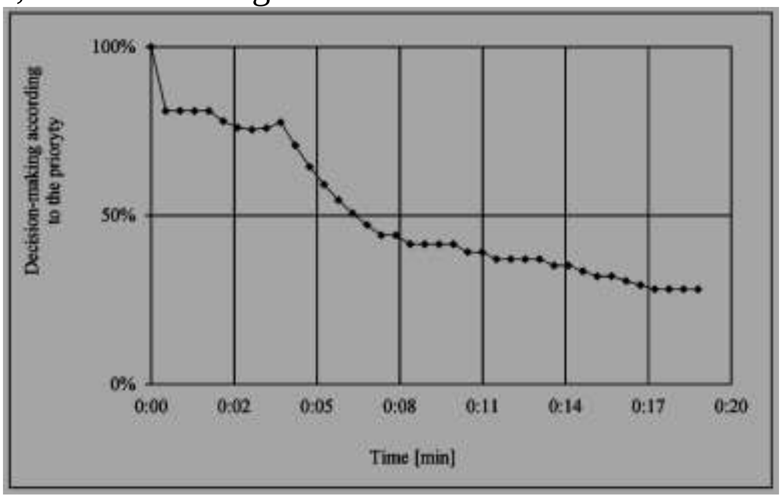


Figure 19 - Graph of the probability of rational actions depending on the duration of the simulation in relation to scenario #2

Further actions were performed according to the established procedures, and the curve decreases over time. The final result of the probability of taking a rational action is 28%, which corresponds to the value 2 of Table 5.

Putting values 4 and 2 in the risk matrix, we get the final result at level 8 (yellow, Table 6).

Table 10 - Conditions for organizing test examinations for Scenario 2

Key indicators	Elements
Infrastructure	Audience

	Lab
Terms	Without a teacher
	No time
Tools for aircraft parts	Present
Other	Summer time
	Daytime
	Instructions - present
	Joystick intensity - medium
Aircraft parts	Assembly with tools
	Disassembly with tools
Helicopter units	Valve H-5810-270
	Check valve 636100
Classes	Class 1
	Class 2
	Class 3
	Class 4

In Scenario #2, an additional factor of working with tools for aircraft parts was introduced (Table 10).

The difficulty level of Scenario 2 was 73% (Table 5). Figure 20 shows the test results.

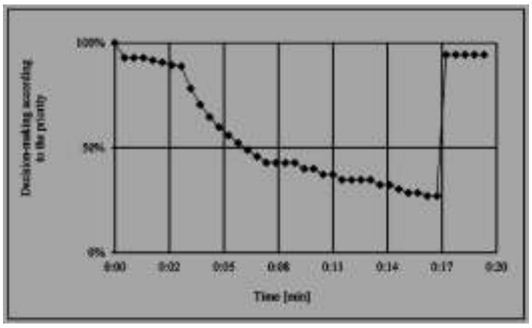


Figure 20 - Graph of the probability of rational actions depending on the duration of the simulation in relation to scenario 2

During the training, the trainee had to perform 30 activities at an aircraft repair site in the correct sequence. Twenty-four tasks were performed, four of which were performed incorrectly, and six tasks were not performed. Since the technician was in the danger zone during the simulation, the training was interrupted. The situation occurred in the 17th minute of training. This is shown in Figure 20 as a sudden increase in P. The final result of the probability of performing a rational action is 97%.

Based on the risk matrix, a final score of 20 is obtained according to Table 6, in red.

When organizing Scenario #3, the element MV-1200 electric motor was introduced, the conditions for organizing the test studies are presented in Table 11.

Table 11 - Conditions for organizing test examinations for Scenario 3

Key indicators	**Elements**
Infrastructure	Audience
	Lab
Terms	With a teacher
Other	Timed
	Daytime
	Instructions - present
	Joystick intensity - low
Aircraft parts	Assembly
	Disassembly
Helicopter units	MV-1200 electric motor
Classes	Class 1
	Class 2
	Class 3
	Class 4

The difficulty level of Scenario 3 was 75% according to Table 5. The results of the test are shown in Figure 21.

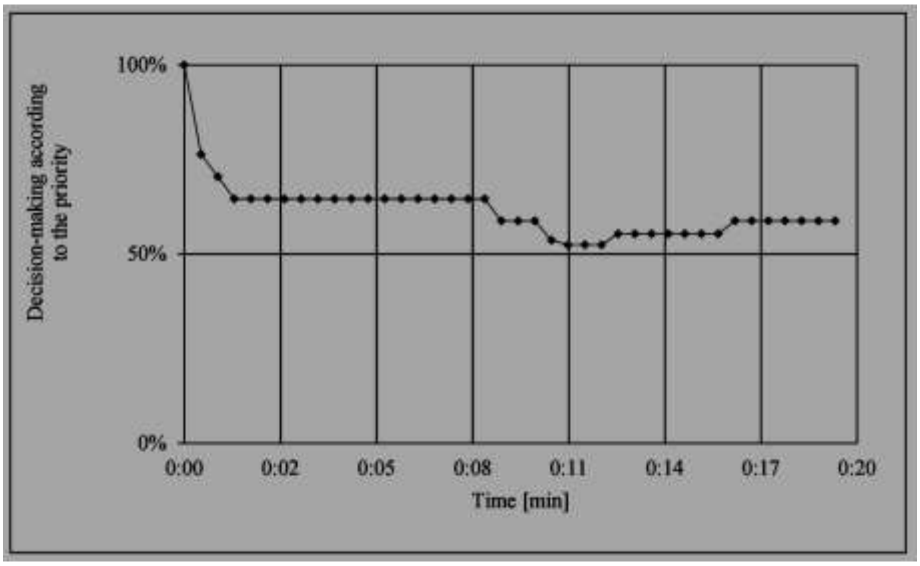


Figure 21 - Graph of the probability of taking rational actions depending on the duration of the simulation in relation to the scenario

The training system involved performing 15 actions in an appropriate sequence. The participant performed nine tasks, one of which was performed in the wrong sequence. In addition, this task was not performed during the entire training period. The P-value was above 50% for almost the entire training period, reaching a high level.

The risk score on the risk matrix is 12, which corresponds to the orange color from Table 6.

Figure 22 shows the results of the risk level assessment for the three test scenarios, interpreted on the basis of the risk matrix. The level of complexity of a particular scenario does not always imply an increase in the risk level assessment; an example is Scenario #3. The same is true for the number of tasks.

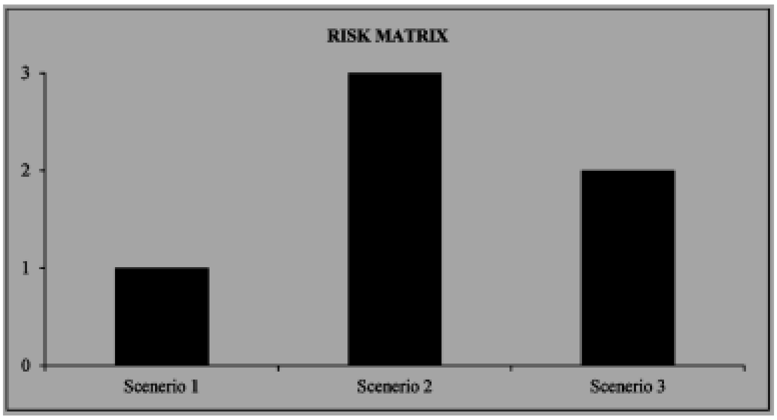


Figure 22 - Risk Assessment of Test Scenarios.

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 simulation duration. It also takes into account any changes made to the simulation during its execution. With this approach, the instructor can monitor the level of difficulty of the scenario on a continuous basis, and thus check the trainee's performance of the tasks. In addition, it is a useful tool to improve the level of training.

In addition, after several simulations with the same tasks, the instructor will be able to identify the most difficult tasks for specialists and subsequently pay special attention to these aspects in the educational process in order to increase the efficiency of action at the aircraft repair site. The use of an algorithm that evaluates the behavior of trainees under certain conditions during virtual reality training may allow for training without the presence of supervisors.

Conclusions of the third section

This section presents the provision of DTM, associated with the development of a method and algorithm for calculating the assessment of practical competencies of the aviation engineering course trainees in VR - 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.

The calculation method can be used for different types of training simulations, be they police, medical, fire or industrial simulations. The algorithm developed allows it to be used in VR simulations of other life-threatening situations.

The proposed algorithm can be implemented in training courses in the field of actions in hazardous or contaminated areas. This solution would be especially beneficial for emergency responders working in refineries and other chemical industry centers. Moreover, the mathematical basis of the algorithm makes it easy to adapt the training to the needs of fire departments as well as police rapid response squads.

The development of this provision is related to further research associated with the development of new scenarios with different levels of complexity of events in which civil aviation personnel can participate.

The use of an algorithm that evaluates the behavior of trainees under certain conditions in virtual reality training can allow for training without the presence of instructors and teachers.

4 DEVELOPMENT OF THE SOFTWARE AND METHODOLOGICAL SUPPORT FOR THE DTM

Creating small virtual reality projects does not require much training or scientific-methodological approach. However, when repairing helicopter equipment, due to the unwieldiness of VR units, applications as projects become larger and more complex, with increasing requirements in the initial stages of design.

The thesis proposes to introduce a conceptual approach to the development of new DTM software, which would be useful to developers of infocommunication and automated systems, programmers, instructors and teachers of digitalization of technological processes.

This support is called software and methodological and is a set of documentation and procedures aimed at the implementation of DTM processes with the use of effective software applications, according to Figure 4.

Consequently, according to formula (15), the result of the software and methodological support $\left[SW(\dot{VR})\right]$ - software module, $\langle T_1 \rangle$ - technical documentation (regulations) for the development of $\dot{VR}$ и $\langle T_2 \rangle$- technical documentation for use/operation $\dot{VR}$.

4.1 Technical regulations for design $\dot{\mathrm{VR}}$

As mentioned in section 2, among the tools for developing virtual reality projects are the following software tools: *Solid Works, Blender3D and Unreal Engine 4.*

In all stages of participation should take part experts - specialists to ensure the results of simulation to the real process of repair of helicopters.

Step 1: Digitization and Texturing Processes

Analyzing the global trends in computer aided design systems, we can conclude that now there is another qualitative transition in the development of 3D-modeling - in the direction of unified integrated solutions. The structure of the Solid Works package is as follows:

− Basic solution that includes 3D modeling of parts and assemblies, express strength and kinematics analysis, drawing design, import/export of geometry from other systems, API interface;

− More than 300 specialized modules solving various application tasks, such as data management, technological preparation of production, etc.

The most common features of Solid Works:

− a special library with a variety of standard components and parts, containing parts with different purposes and parameters, so you can quickly find any object or use a standard component as a part to modify it;

− snapping, the most interesting and relevant feature of the program, allows you to make coordinate connections directly in the model, with the working elements of the designed object linked together to prevent distortion of the constructed object when making the necessary changes to the model itself;

− work with different equations, because the program has the ability to link the entire model with the equations taken out in a separate created document of text format, and when you change one element in the object will happen a synchronous change in the entire model;

− automatic drawing directly from the model - the feature is practically indispensable for designing a variety of technical products, so you can get drawings from the model in just a few clicks of the computer mouse;

− the ability to cross-link surfaces, which allows you to get a solid model that will be suitable for reproduction on the used 3D printer.

As a result of the study, an integrated procedure combining digitalization (DG) and texturing (CL) according to formulas (9) and (10) was developed using Solid Works software. In a step-by-step structure, the algorithm of the proposed procedure is as follows.

Step 1. Select the plane on which the sketch will be built.

Step 2. If there are not enough standard planes, set up a new plane.

Step 3: Draw sketches on the planes.

Step 4. Choose what principle will be used to create a 3D model from the finished sketches (pull along the axis, wrap around the axis, select several sketches for the profile and create a smooth transition from one to another, cut something out, round something, also by different methods, etc.).).

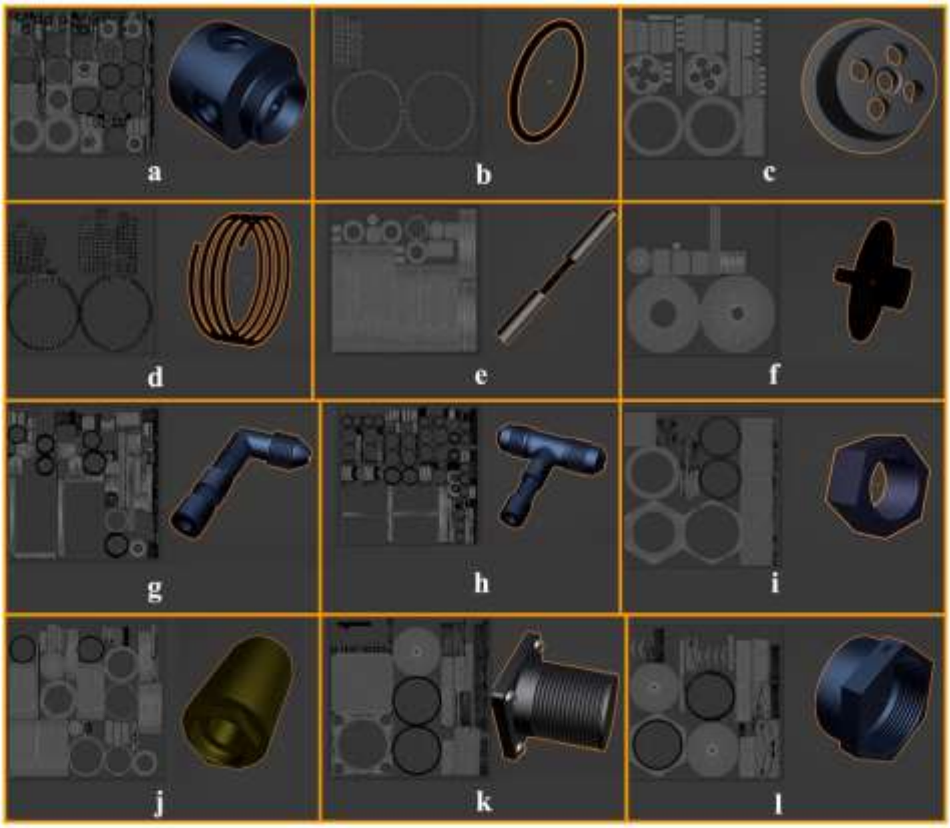
Step 5. To import into Blender3D, save in the *.STL format (turning a solid model into a polygonal model). The *.STL format stores information about the object as a list of triangular faces that describe its surface and their normals.

Example 1. Figure 23 shows examples of the results of the procedure including DG and CL parts of the GA-192T unit of the MI-8 AMT helicopter.

Step 2: The layout process

This stage is implemented using the object-oriented program Blender3D. The functionality of this program allows you to create three-dimensional computer graphics, including not only modeling, but also animation, visualization, game creation, video processing.

As a result of the study, we formalized a procedure that implements the layout process (LY) according to formula (11) in the Blender3D software package. In a step-by-step structure, the algorithm of this procedure appears as follows.



a - Housing (1 pc.); b-O-ring (5 pcs.); c- Saddle (1 pc.); d-Spring (1 pc.); e-Axis (1 pc.); f–Stopper (1 pc.); g - One-sided square (1 pc.); h–Double-sided square (2 pcs.); i-Nut (3 pcs.); j-Electromagnet (1 pc.); k - solenoid valve (1 pc.); l - Lid (1 pc.).

Figure 23 - Building a 3D model of the GA-192T unit parts of the MI-8 AMT helicopter

Step 1. After exporting a 3D model in the *.STL format, you need to add anti-aliasing.

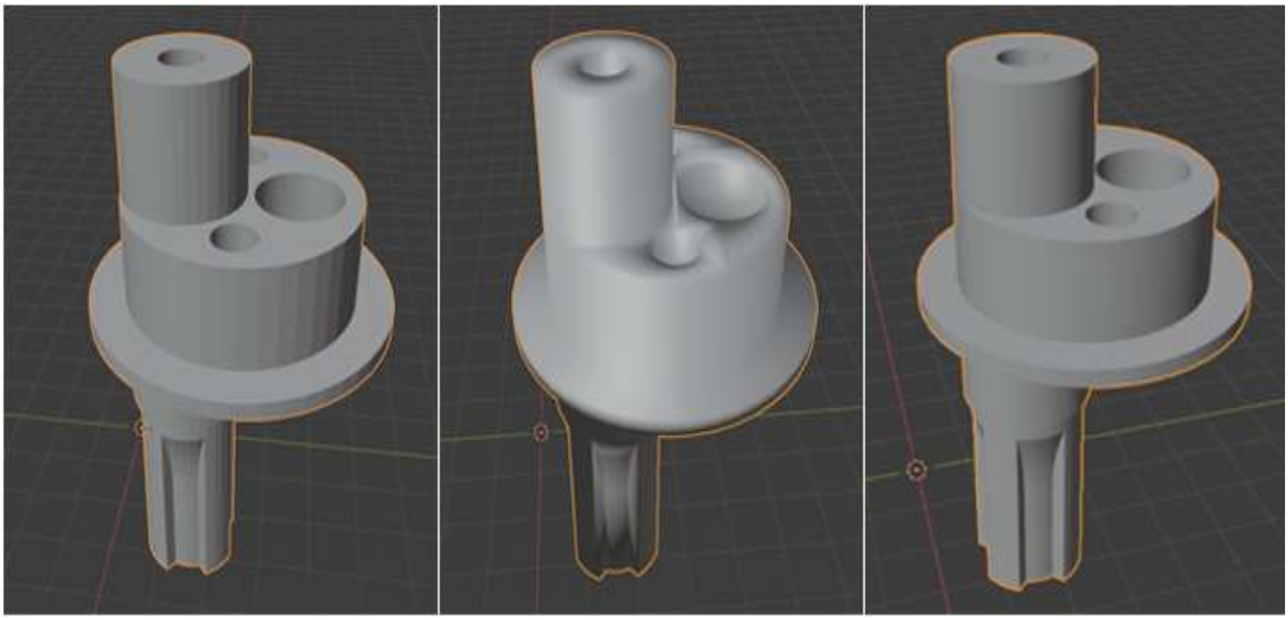
Step 2: Make an X and Y sweep (U and V) for each polygon;

Step 3. Assign materials to polygon groups, if necessary

Step 4. To import into Unreal Engine 4, export to the *.FBX format. The *.FBX format stores the parametric data for each polygon, information about the scan, about smoothing, about materials).

Example 2. Consider the implementation of the testing phase.

The smoothing of the planes, performed in the first step, is first performed using a shader. Next, you need to make the 3D model visually indistinguishable from the original. To do this, groups of auto-smoothing normals are created (Figure 24). Normals are vectors that are used to determine how light bounces off a surface.



After exporting . STL *The result of smoothing with a shader* *The result of auto-smoothing of normals*

Figure 24 - Smoothing a 3D model with Blender3D software

Experimentally it is noticed that the number of points, faces, planes as a result of smoothing does not change, as shown in Figure 25.

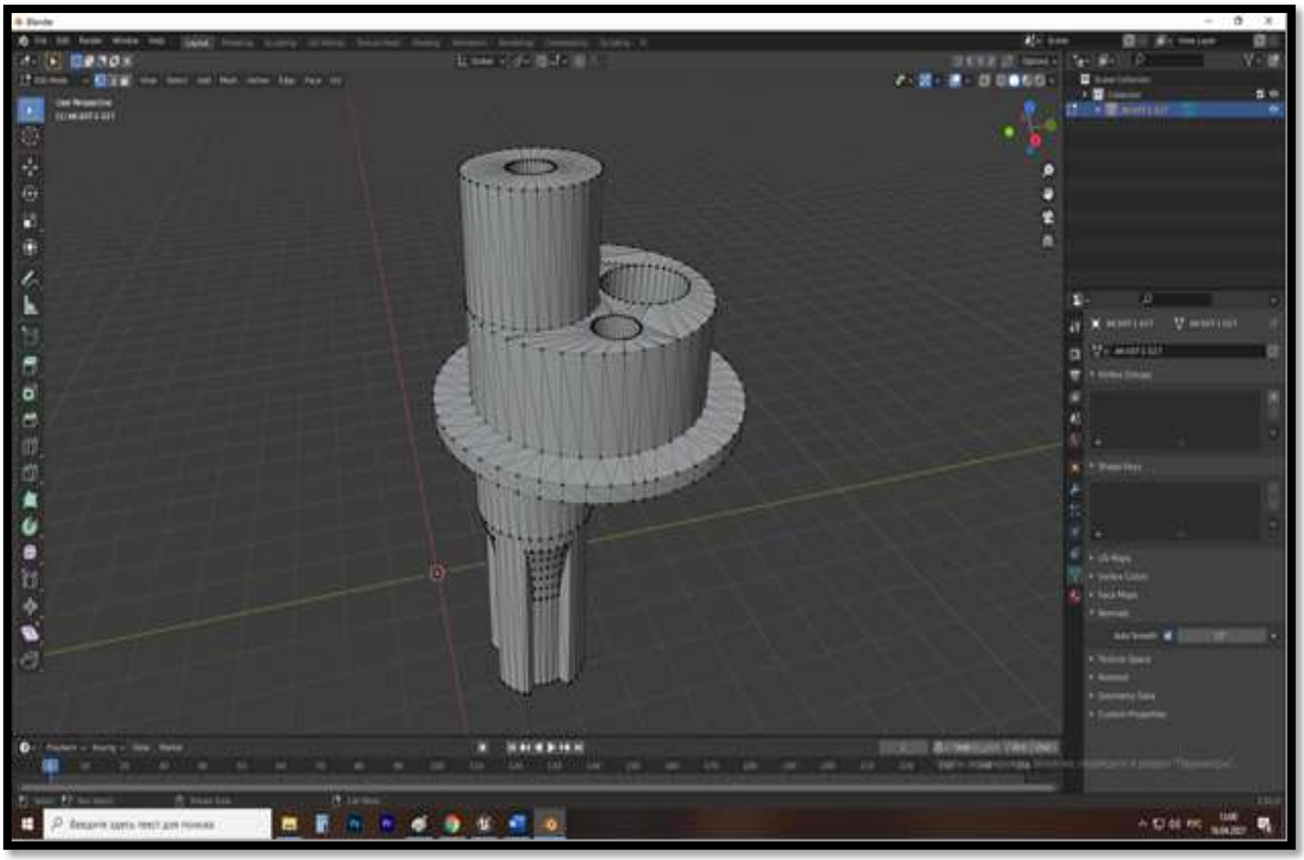


Figure 25 - 3D model of the part after processing in Blender3D

The number of points, faces, and planes retained means that the CPU load has not changed, since Blender3D uses the same data to build the model as it did when importing the STL model from Solid Works. But the calculation of light reflection is now changed - the GPU (video card) is connected.

Without leaving edit mode, select a group of planes to which you want to assign one common material. This is done for UV scanning of planes from 3D-model to 2D-texture. In the example under consideration, as shown in Figure 26, the entire part consists of one material and will not contain pre-drawn textures, but for the material to be displayed correctly this step must be done, otherwise you get the quality - "as if someone had pulled a baby balloon on a zeppelin".

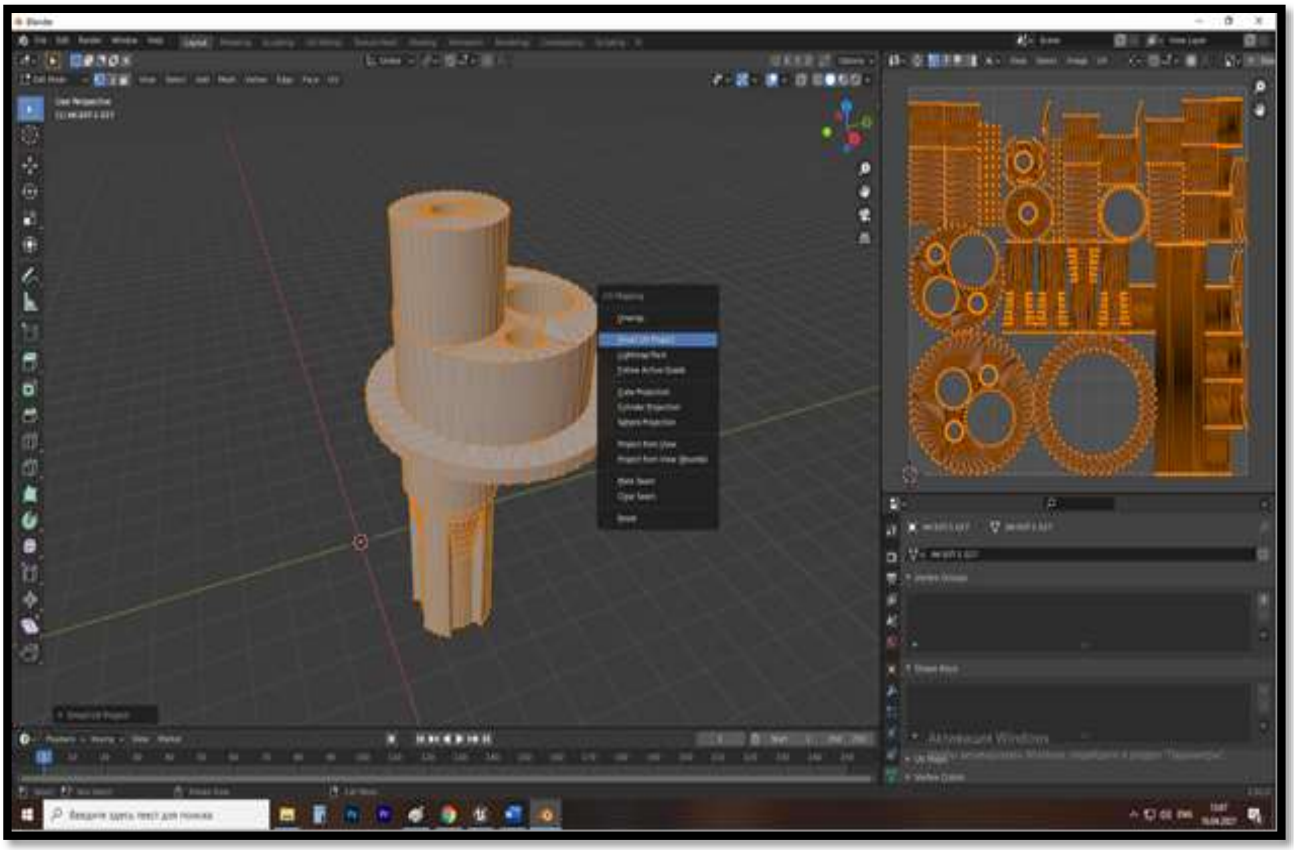


Figure 26 - Part flattening in Blender3D software

Next, without exiting edit mode, create a material slot for each part. In this example, there is one type of material. The number of slots can be equal or even greater than the number of planes. Setting up material in Blender3D makes no sense, because it is difficult to export the commercial "chips" of the rendering of individual 3D editors to each other. Material tuning will be done in the final program - Unreal Engine 4.

The final step in Blender3D is to export it in the *.FBX format for import into Unreal Engine 4. The STL format stores only the parametric data of the 3D model shape. The FBX format stores additional information about antialiasing, sweep, and material.

Step 3: The process of creating a software application

This stage $[\mathrm{SW}(\dot{\mathrm{V}}\mathrm{R})]$ is implemented in accordance with expression (13) and using the software Unreal Engine 4 (hereinafter - UE4), a toolkit for game and application development, which has a wide range of possibilities: from creating 2D games for cell phones to AAA-projects for consoles.

Developing in Unreal Engine 4 is very easy for beginners. Combined with a user-friendly interface, it allows you to quickly produce working prototypes.

Consider the merits of the Unreal Engine environment:

− One of the most popular engines today - Unreal Engine, developed and supported by Epic Games, which are one of the pillars of the industry, especially in the technological part, because the level of quality and number of features leave many competitors behind;

− there are certain conditions and royalties when you buy it, but all the tools are available immediately and in full to create a AAA-quality game, and the wide functionality implies a challenging interface, especially for beginners;

− There is everything you need for designers, artists, and programmers, and all the source code is open - any part can be customized to fit the project, which makes the system more flexible;

− Due to its openness, UE has a large community, and fixes for bugs found by the community quickly get into the official updates.

− multiplayer “out of the box”, i.e. in fact, after launching the editor in a few clicks you can create a project that already has an online game, and, given the growth of multiplayer games and the bets of large companies on online modes with multiple players, this is a serious advantage, which, for example, does not have Unity.

Among the many disadvantages, the only downside of Unreal Engine is the overpriced in-store content.

This stage of VR software development in Unreal Engine 4 is quite easy to implement.

In a step-by-step structure, the algorithm for this procedure is as follows.

Step 1: Import the FBX model.

Step 2. The material associated with the imported FBX model is added to Unreal Engine as a separate file.

Step 3. Configure the added file.

Step 4: Add user interaction logic to the 3D object in VR mode.

Example 3. To develop a VR-application of the assembly process of the electromagnetic crane GA-192T in UE4 when repairing the helicopter MI-8.

Getting Started. Each scene/map/level (in UE4 the file itself is called *Level*) contains objects (in UE4 everything on the Level is called *Actor*), as shown in Figure 27. Hence the translation variant Level - scene. Actors, do not necessarily contain logic, if you import a 3D model (in UE4 called *Static Mesh* or just *Mesh*) and then just put it on the Level, it (3D model) will also be displayed when you start the application.

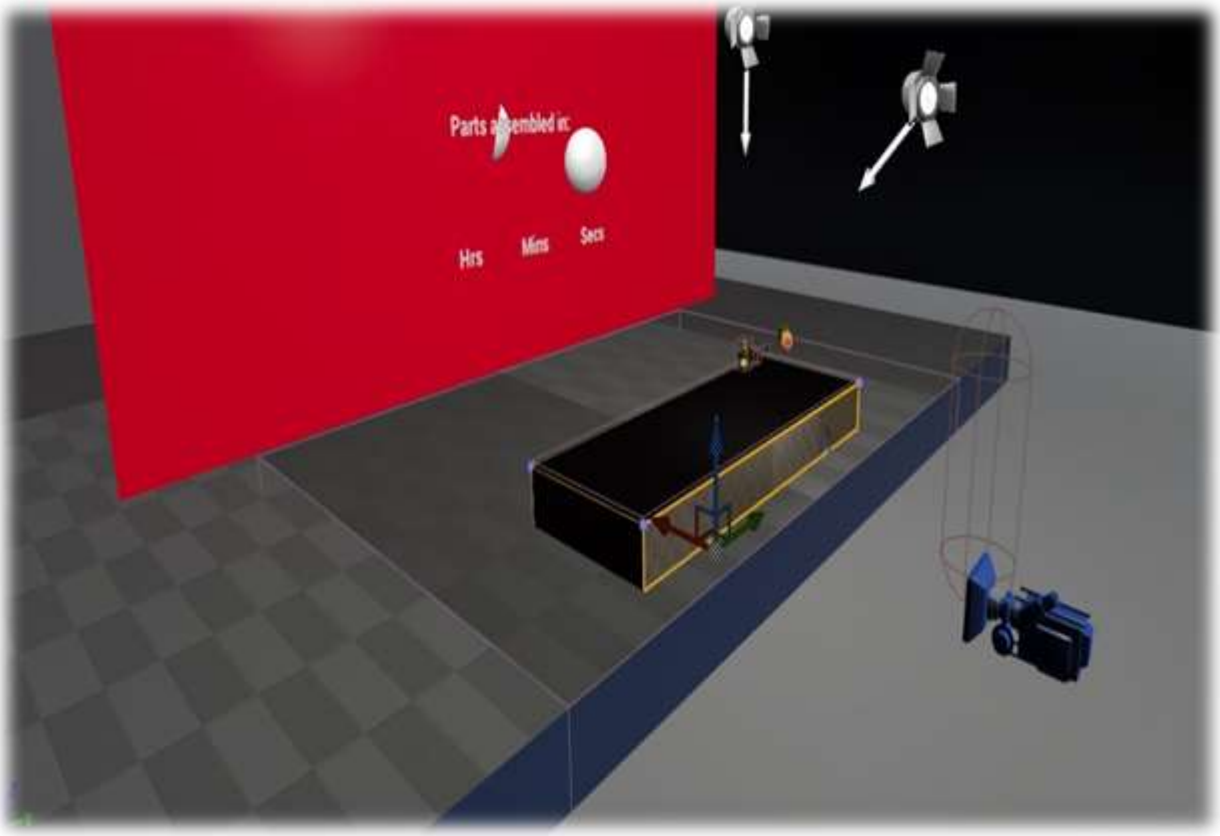


Figure 27 - Level Editor

Level - has both a 3D editor, shown in Figure 27, and a logic editor, in which you can both control the settings of Level itself, and **any** Actor, including those already placed in the *Level Editor*.

Through the *Level Blueprint Editor, according to* Figure 28, you can even access *the Static Mesh* (which initially contains no logic) and adjust the logic behavior.

Level Blueprint Editor - can contain its own set of variables, functions, macros, event managers.

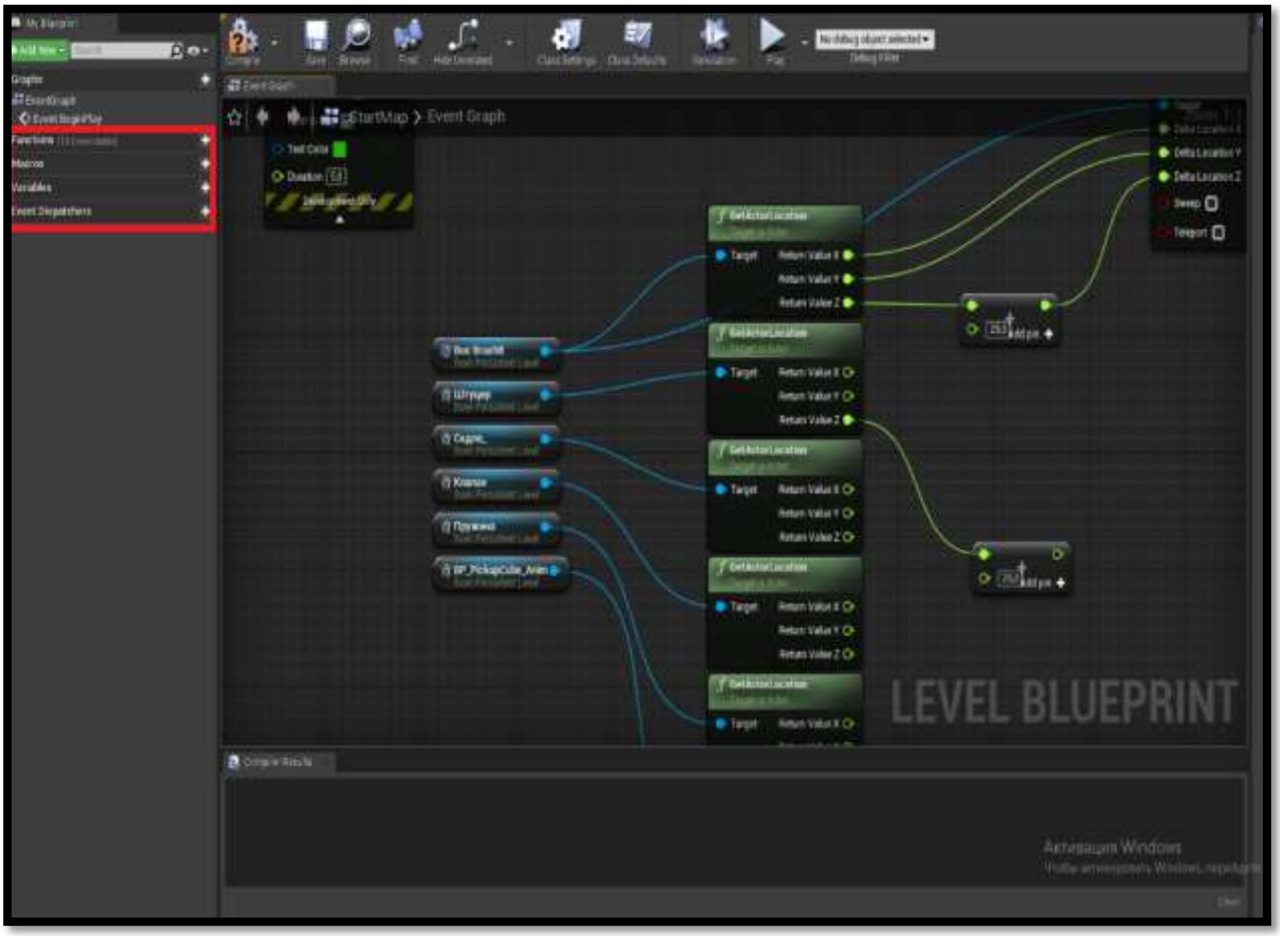


Figure 28 - Level Blueprint Editor

The Level Blueprint cannot be accessed from other places (classes), so if you plan to create variables or functions that will need to be called from other *Blueprints* (analogous to *.cpp) it is better to create them in the Blueprint that belong to that level. And then call them in the Level Blueprint.

Consider the example: ***LEVEL_GA-192T_A***

For convenience, the names of the levels are given as follows:

Lvl_NAME_TYPE,

where *Lvl*- Helps to understand that this type of Blueprint is exactly - Level; *NAME* - Name of the unit; *TYPE* - Type of operation at this level.

For now, let's focus on two types of work:

A - *Assembly*;

DA - *Disassembly* (disassembly of the unit).

At this point the logic is contained, which is used as a check to see if the variables from the other *Blueprint* files are working (Figure 29).

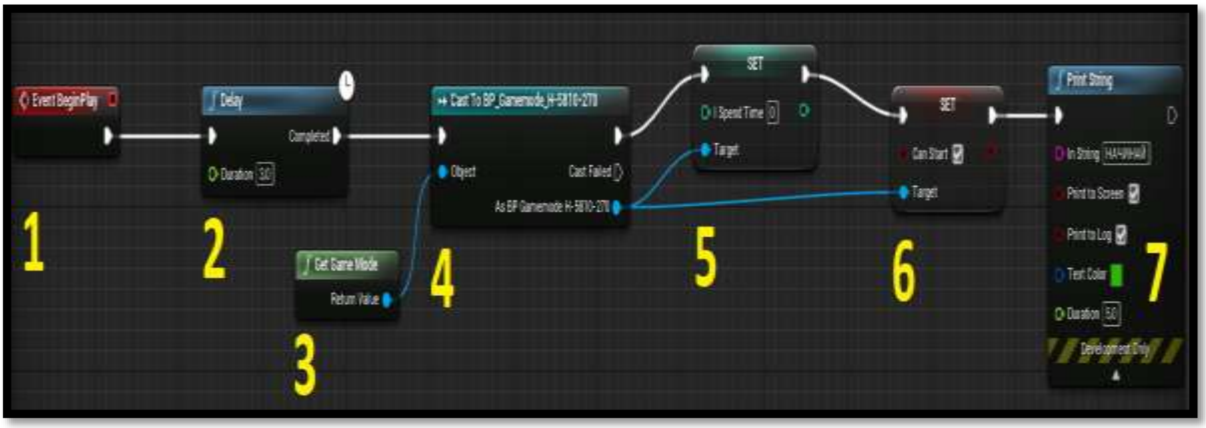


Figure 29 - Logic currently contained in Level_ GA-192T _A

The purpose of the logic in Figure 29: Allow only 3 seconds after starting the unit to begin assembly work.

To achieve our goal, we need the following events, operators, functions, and variables:

1. *Event Begin Play*, a standard Event for almost all Blueprint classes, means that the chain of logic events is triggered when it appears on the level (since this is a Level Blueprint, the logic contained here starts from the very start of the Level).
2. *Delay* - delay before moving to the next link in the chain. It is of FLOAT type and can be set by connecting a variable or by entering it manually. Time in seconds. In this case the delay is set to 3 seconds.
3. *Get Game Mode* - Gives access to Game Mode Blueprint files.
4. *Castto BP_Game Mode_GA-192T* - Indicates which specific Game Mode Blueprint we need to access. From the blue output we get the objects that are contained specifically in that Blueprint.
5. *Set (iSpend Time)* - I am zeroing the variable of int type, to which 1 unit (second) “*BP_Game Mode_GA-192T”* is added every second starting from program start, since we have a delay of 3 seconds before start. It would be more convenient to store the variable with time directly in Level Blueprint, but then we wouldn’t be able to get it in other classes. Each level must necessarily belong to some Game Mode (and now I think that it would be enough to have one for all, if it will be possible to do so, I’ll explain later).
6. *Set (bCan Start)* - Change the BOOL type variable to true. It is referred to in another class “*BP_Pickup_Anim*”, where while it is false you cannot start.
7. *Print String* - In development mode, it outputs anything in text. You can output both on the screen and in log files.

Working with Game Mode. Game Mode, translated as game mode. Binds to a level, and other classes are bound to it, as shown in Figure 30.

Figure 30 - Selecting the Game Mode for this Level

Game Mode is mainly used to store important variables and functions, since you can access it from absolutely any class as long as the Level to which this *Game Mode* is bound is running.

BP_GAMEMODE_GA-192T

Game Mode can be created either for each *Level*, or one for all levels. For convenience, the names of the levels are given as follows:

BP_Gamemode_NAME,

where *BP_Gamemode* - Helps to understand that this type of Blueprint is exactly - Game Mode; *NAME* - Name of the unit.

Variables and their categories. It is better to call variables and their categories as they are, to make them clearer and to avoid confusion later on.

You can put the first letter of "variable type" in front of the name. This is in case you need two variables with the same name but a different type (Figure 31).

In UE4, for convenience, different data types are marked with different colors. As for the basic variables, *bool is red*, *int is turquoise*, and *float is pale green*.

Check Vars - the default is 0 (false).

Monitoring Cars – the default is 0.

Add Vars - the default is 1.

Time - the default is 0.

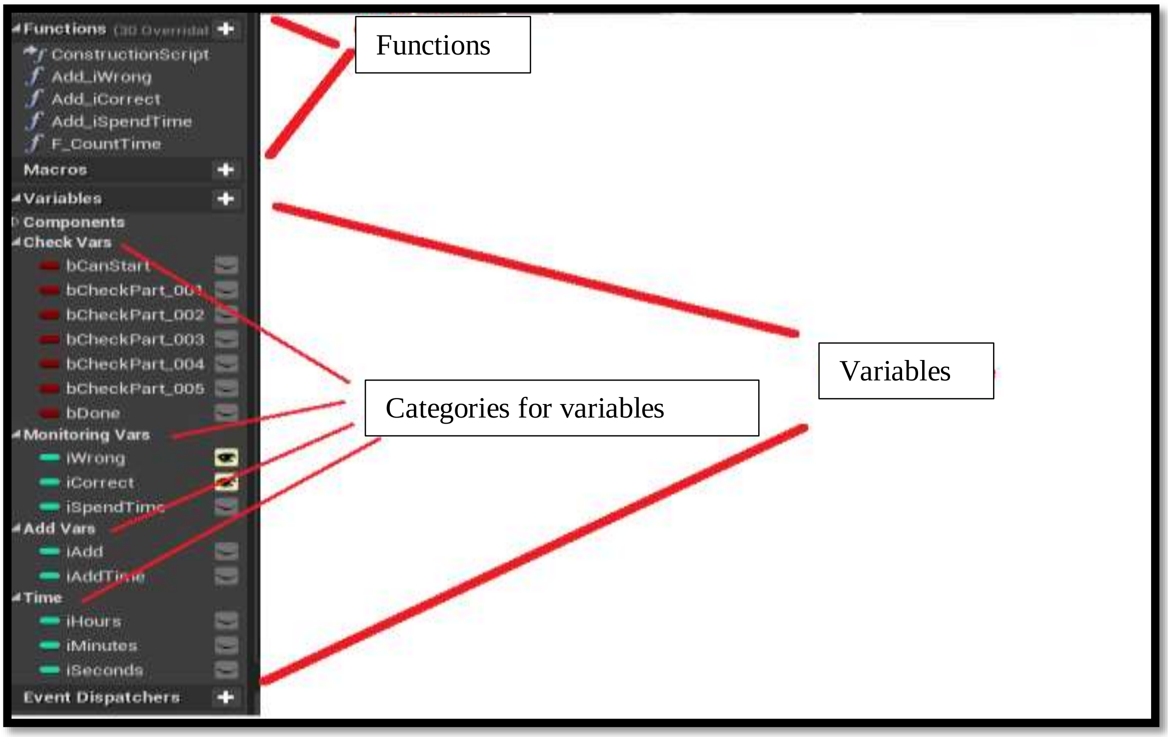


Figure 31 - Contents of functions and variables in BP_Gamemode_GA-192T

A parsing of the meaning of functions and variables will be presented as they appear in the logic. The basic logic that this Game Mode currently contains is shown in Figure 32.

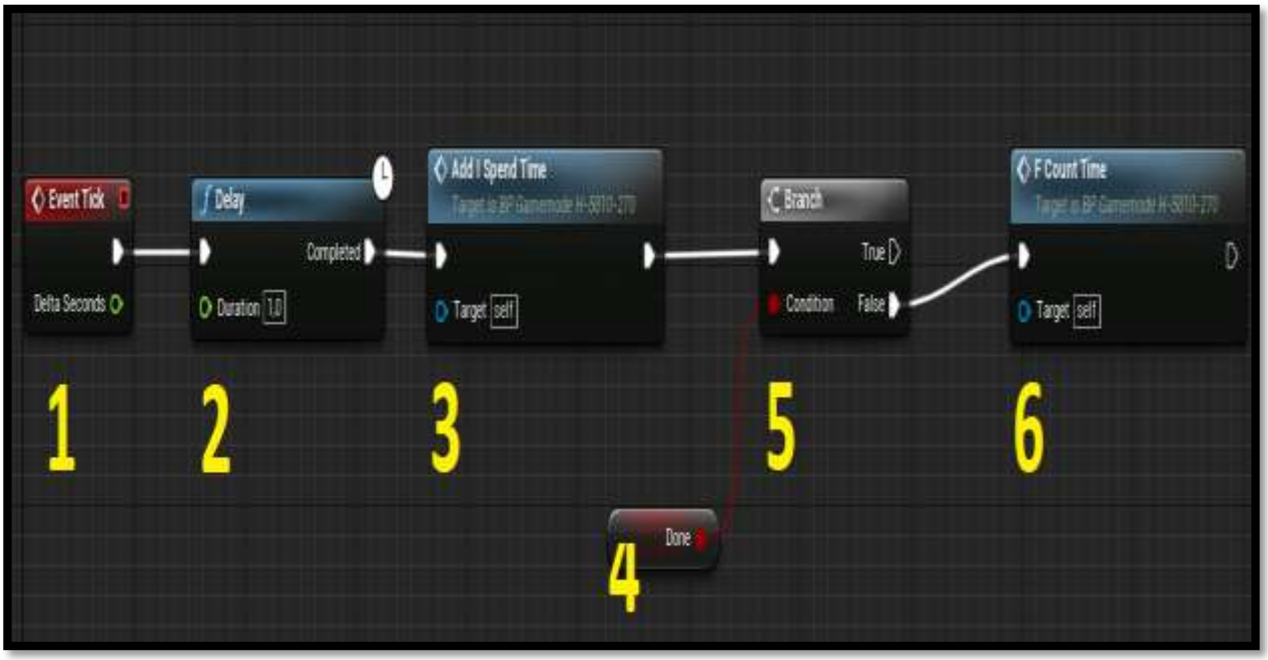


Figure 32 - Basic logic in BP_Gamemode_GA-192T

The purpose of Game Mode, shown in Figure 32: *count the seconds until the job is complete.*

To achieve our goal, we will need the following events, operators, functions, and variables:

1. *Event Tick* - a standard Event for almost all Blueprint classes, means that a chain of logic events is triggered after each frame update. The number of events per second depends on the number of frame updates (FPS - frame per second), which means that the more powerful the device on which the application is running, the more often the event will be triggered. For the stopwatch, this does not work at all. Therefore, we add element 2.
2. *Delay* - delay before moving to the next link in the chain. It is of FLOAT type and can be set by connecting a variable or by entering it manually. Time in seconds. In this case the delay is set to 1 second.
3. *Add_iSpend_Time* is a function that adds 1 to the "iSpend Time" variable. The work of the function is shown in Figure 33.
4. *Get Done* - gets true / false from a BOOL type variable.
5. *Branch* - divides the logic chain by 2, checking the condition and continuing the corresponding logic depending on the result (true / false). In this case it calculates seconds into hours + minutes + seconds until the job is finished.
6. *F_Count_Time* - calculates the seconds on hours + minutes + seconds. The work of the function is shown in Figure 34.

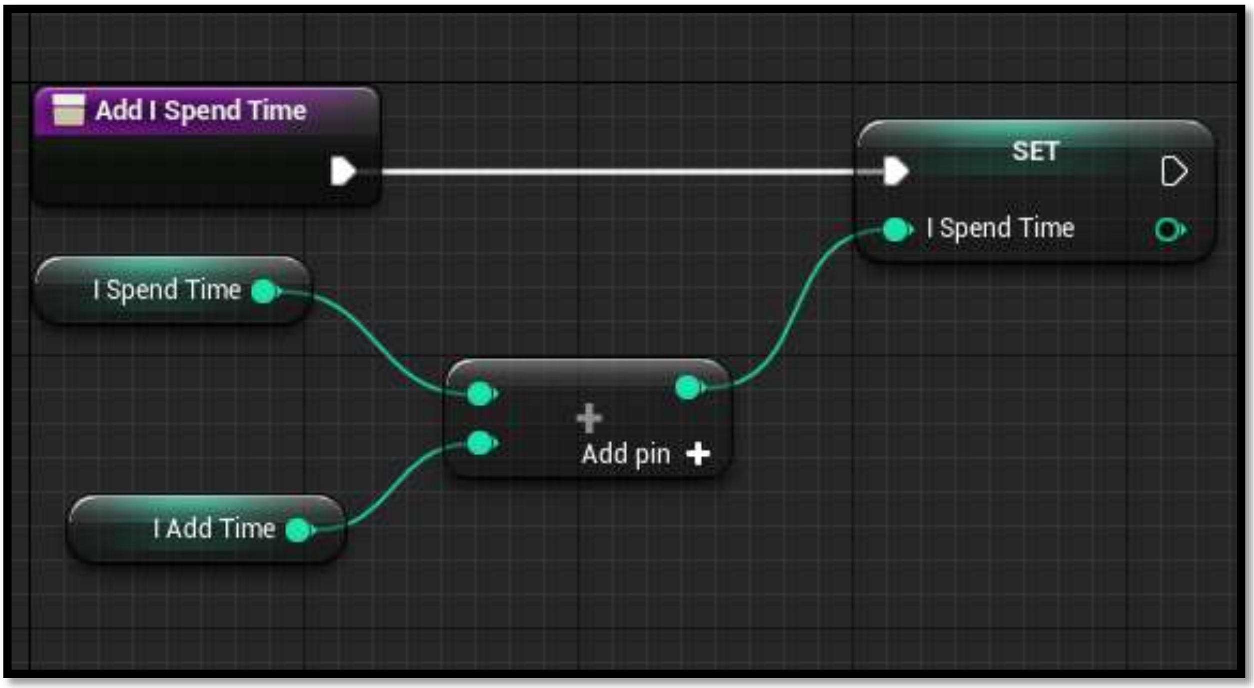


Figure 33 -Ad_iSpend_Time function

The purpose of the logic in Figure 33: add 1 to the iSpend Time variable.

The goal of logic is accomplished in the following way:

1. First the value of the variable at a given time is taken (get) iSpend Time, then 1 is added. This can be done in two ways:
   - or by filling in the box;
   - or by connecting another variable with value 1.
2. Assign a new value to the iSpend Time variable by calling it (set) and plugging in the result from step 1.

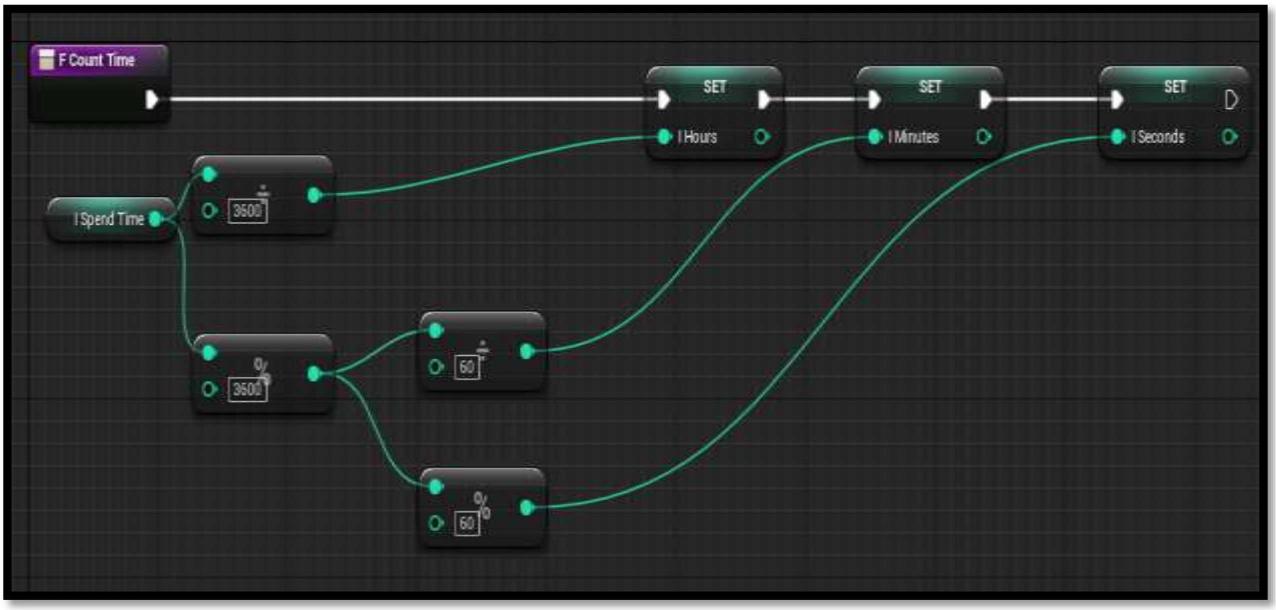


Figure 34 - FunctionF_Count_Time

The purpose of the logic shown in Figure 34: to break seconds into seconds, minutes and hours.

The goal of logic is accomplished in the following way:

1. We take the value of iSpend Time (due to the fact that we operate with integers only) and divide it by 3600 to get the number of hours. We assign the result to the variable iHours.
2. Hours are discarded, you need to know the number of seconds left to get the minutes. To do this, get the remainder of the division of by 3600 using %.
3. Finding out the remaining seconds, divide them by 60, we get the number of minutes. We assign the result to the iMinutes variable.
4. Once we have the hours and minutes, we proceed to the seconds. To do this, we need to get the remainder of the division by 60 with %, as a result, we will get the number of seconds. We assign the result to the iSeconds variable.

If necessary, you can add any number of parent and inherited Actors per Level.

Figure 35 shows the Main Actor (Unit Casing) on the right, which includes additional Actors (the parts that make up the Unit) to the left of it. All Actors except the Main Actor are invisible with Level startup.

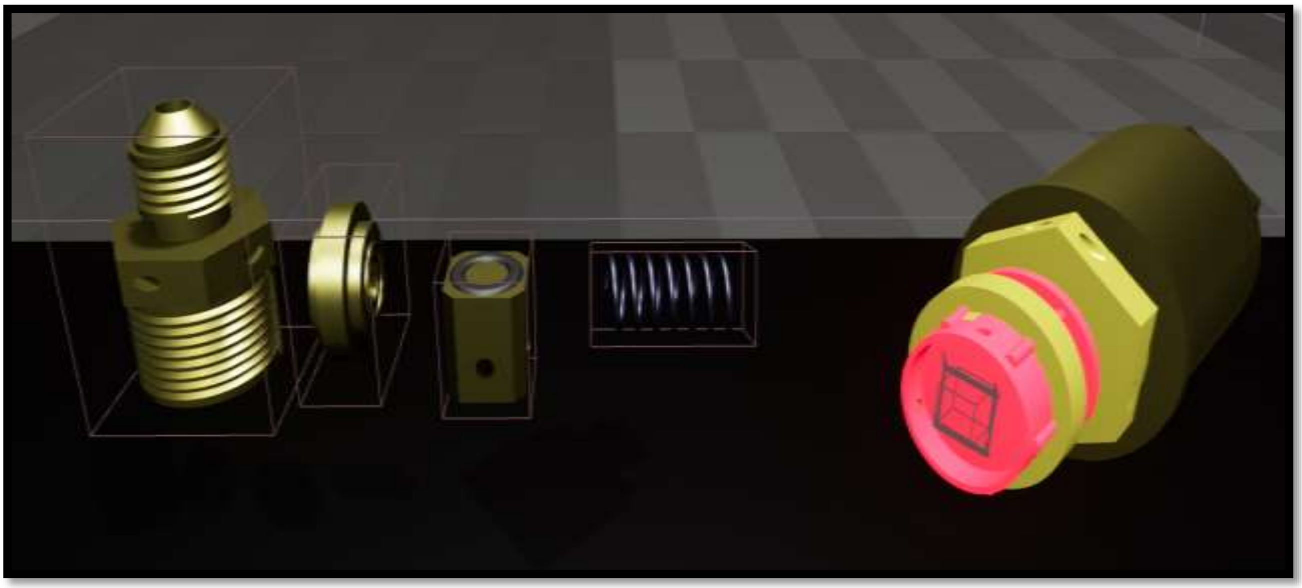


Figure 35 - Main Actor and its Actors

Figure 36 shows the logic of the unit assembly.

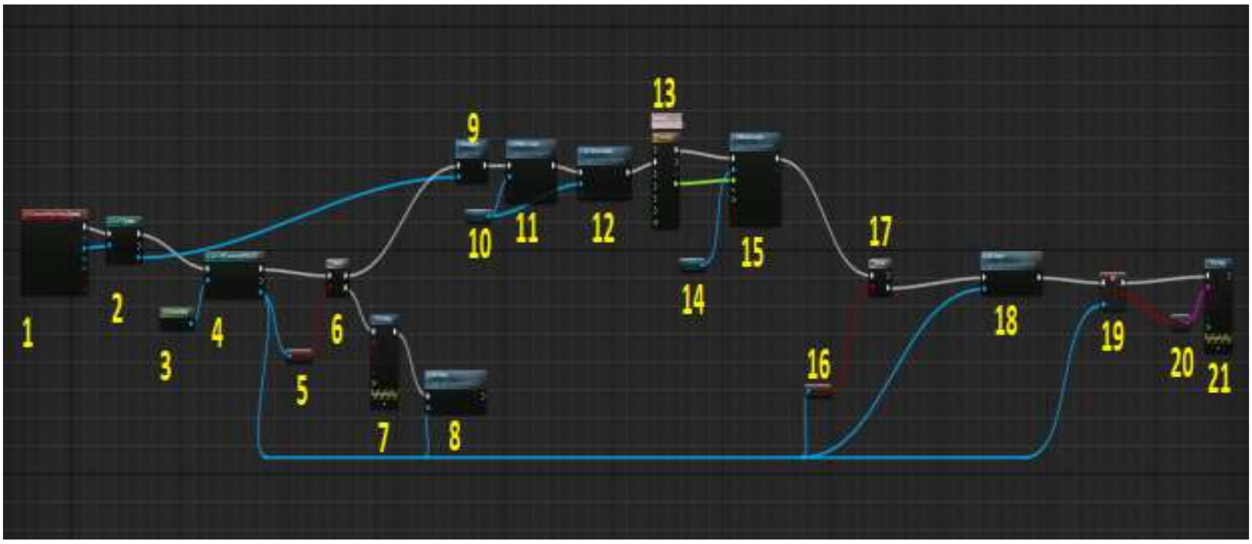


Figure 36 - Assembly Logic of the Unit

As you can see from Figure 36, before you start programming only the “Unit casing” is visible, to activate the invisible elements you need to perform a number of manipulations.

It is not possible to display the complete logic diagram, due to the fact that it is impossible to display all the blocks on the screen. For such purposes, there is a site that knows how to renderBlerint(s) so that they are readable (https://blueprintue.com/).

4.2 Technical regulations for use/operation VR

To apply VR you must first launch the application **START PROJECT 2** in **the Unreal** Engine.

Start working with the application according to the following step-by-step algorithm.

Step 1: Launch the Oculus application, which shortcut is located on the desktop of your laptop, computer, or tablet, by activating the oculus icon.

Step 2. Connect Oculus Quest 2 Virtual Reality Helmet to your laptop using the Oculus Link USB cable, as shown in Figure 37.

Figure 37 - Oculus Link USB Cable

Step 3: Connect the Helmet. On the left side is the headset power button and next to it is the operating indicator, as shown in Figure 38. Make sure that the headset is charged.

Figure 38 - Turning on the headset

Step 4: Put the Oculus Quest 2 Virtual Reality Helmet on your head as shown in Figure 39.

Figure 39 - Oculus Quest 2 Virtual Reality Helmet

Step 5. Click “Allow”, after the headset prompts **“Allow data access”**.

Step 6. Draw new boundaries of the protection system with the manipulators. To do this, click on the “Create protection system” button and follow the further instructions:

- confirm the distance to the floor;
- determine the work area;
- make sure that there are no foreign objects in the working area;

Step 7. Press the **“O”** (Oculus) button for 2 seconds, as shown in Figure 40.

Figure 40 - Analog stick and three additional buttons “A”, “B”, “O” on the manipulator

Step 8. After the “Menu” appears, open “Settings” by clicking on “Time” (the button is on the right panel) and “**Enable Oculus Link”.**

Step 9. After turning on the “**Oculus Link”,** remove the headset from your head and open the **“Steam VR”** application on your laptop (PC) by double-clicking the shortcut on the desktop.

Step 10. Authorize (enter login and password).

Step 11. Make sure that “Steam VR” software sees the headset and manipulators , as shown in Figure 41.

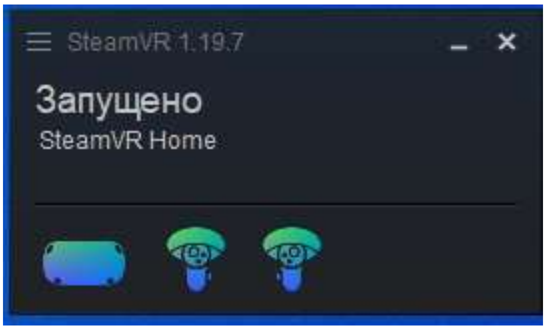


Figure 41 - “Steam VR” software

Step 12: Launch START PROJECT 2 by double-clicking on the desktop shortcut

Step 13. After opening the SP2, make sure that the VR Preview mode is selected, as shown in Figure 42.

Figure 42 - Selecting VR Preview mode in the SP2 app

Step 14. Make sure that the headset and arms are connected in Steam VR. If the Steam VR Software **does NOT** see the headset and arms, close all applications and start at step 1.

The software and methodological support of the DTM of the helicopter repair process meets high requirements, including:

– innovation, because it considers the use of modern software products based on 3D-modeling and VR-technologies for practical and laboratory classes;

– effectiveness because it includes components of teacher and learner functions;

– Structured - teaching material that highlights the most essential elements of the topic, identifying goals and technologies for solving practical problems;

– Integrity - the ability to work individually, with a teacher and in small groups;

– Increasing the information capacity of the educational process through the use of computerized ways of presenting educational material;

− the ability to perform creative and research activities by creating VR applications, creating projects and resources, digital modeling and simulation of complex phenomena and repair processes, solving tasks with the help of information and learning environment;

− Increased interest and awareness of the importance of the educational process;

− implementation of self-monitoring and correction of the educational process with diagnostic results;

− The teacher is able to constantly update the training material, adapt and supplement the already laid in the database VR applications, implementing an interactive approach to learning;

− The quality and effectiveness of learning increases due to the simultaneous impact of graphic, audio, and video information on students.

Conclusions of the fourth section

The software and methodological support proposed by the author of the thesis is a set of documentation and procedures aimed at the implementation of DTM processes using effective software applications and training and methodological complexes.

The result of the software and methodological support $\left[SW(\dot{V}R)\right]$ - software module, $\langle T_1 \rangle$ - technical documentation (regulations) for the development $\dot{V}R$ и $\langle T_2 \rangle$ - technical documentation for use/operation $\dot{V}R$.

Tools for the development of software applications mathematical and algorithmic support of the DTM repair of helicopters using software tools: *Solid Works, Blender 3D and Unreal Engine 4.*

Both technical documents are complex structures that include step-by-step and step-by-step implementation. All are accompanied by clear examples for implementation.

At all stages, experts should take part - specialists to ensure that the results of the software correspond to the real repair process of helicopters.

Programmatic and methodological support meets high requirements for innovation, efficiency, structure and integrity, etc.

In general, the teacher receives an excellent teaching material with the possibilities of updating, adapting, interactive learning and formation of databases of 3D-models of VR - virtual reality applications. But the main feature is the simultaneous impact of graphic, audio and video information for students, which is relevant to improve the quality and effectiveness of learning.

5 IMPLEMENTATION OF DTM HELICOPTER REPAIR PROCESSES

From the first chapter of the dissertation work it follows that at JSC “Aircraft Repair Plant #405” the main technological process at the production to provide a range of services in the aviation market is the repair of helicopter equipment.

The developed DTM, designed for digitalization and repair, has found its application, i.e. has been implemented, at this enterprise.

5.1 Training complex “Helicopter repair”

Within the limits of the project on grant financing AP08857126 of Committee of Science of the Ministry on a theme: “Development of a complex of interactive training programs on technological processes of repair of aviation equipment”, the JSC “Aircraft Repair Plant #405” ordered the innovative educational product, in addition having financed on the sum 3 million tenge.

According to the terms of reference, the complex must meet the following requirements:

− form a database of repaired units and parts based on 3D, VR technology and artificial intelligence to calculate costs, forecast labor and financial resources, which will serve as a fundamental basis for the digitalization of production, optimization of technological processes, improving workplace safety;

− provision of quality educational practical competences with minimum financial expenses, maximum self-training, insignificant time involvement of instructors-mentors and control of training material assimilation taking into account the risk of actions on the repair site.

JSC “Academy of Civil Aviation”, perfectly coped with the task by offering the “Training complex “Repair of helicopter equipment”. Its structural diagram is shown on Figure 43, and the front panel of the interface is shown on Figure 44.

As can be seen from Figure 43, the complex includes 25 digital models of helicopter aggregates subject to overhaul, current and local repair:

1) Check valve 636100;
2) Electromagnetic crane GA-192T;
3) EMCO-M(T) electromagnet;
4) Headlamp FR-100;
5) 748B fuel pump;
6) Electric motor EM-662T;
7) EMT-2M;
8) Automatic unloading machine GA-77B;
9) Pressure reducing valve UP-25/2;
10) 463B electric centrifugal pump;
11) Electric motor MV-280B;
12) Frequency cutoff box KOCH-1A - 2 series;
13) Electric centrifugal pump ECN-91B (C);
14) MP-100C electric motor - 3rd series;

15) Pressure switch SD-29A;
16) MST, MST-A pressure switch;
17) Electric fan DV-302;
18) Air compressor AK-50T1;
19) Fire extinguisher UBSH-4-4;
20) Automatic pressure machine AD-50;
21) Emergency power on valve GA-59/1;
22) Reduction gas pedal UP03/2M;
23) Sealing valve 242-5800-10;
24) Tachometer meter ITE-1 (2);
25) Sensor D-1M (2M).

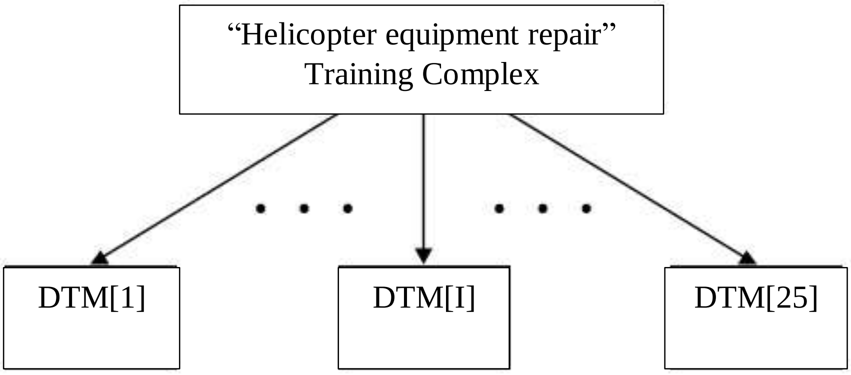


Figure 43 - Structure of the "Helicopter equipment repair" training complex

Figure 44 - Front panel of the "Helicopter Repair Training Complex" interface

It follows from the above that the "Helicopter Repair Training Complex" is a relational database [86-91] based on the scientific-theoretical positions of relational algebra: tables, relations, rows, columns, primary key, relational algebra, etc.

All operations in a database are operations (manipulations) with tables consisting of rows and columns and has a name and code that are special and unique in principle. Each table is a specific object, and their union is a complex of objects (entity), controlled automatically or by operator action.

According to the theory of databases [92-97], the training complex, reflecting helicopter repair, clearly defines the subject area unambiguously and inconsistently, since it satisfies the condition of integrity.

Each DTM {I} was developed taking into account all types of collateral and according to the conceptual approach proposed by the author of the thesis, and which are described in detail in this paper.

Figure 45 shows the structure of the DTM, Figure 46 - the external interface panel.

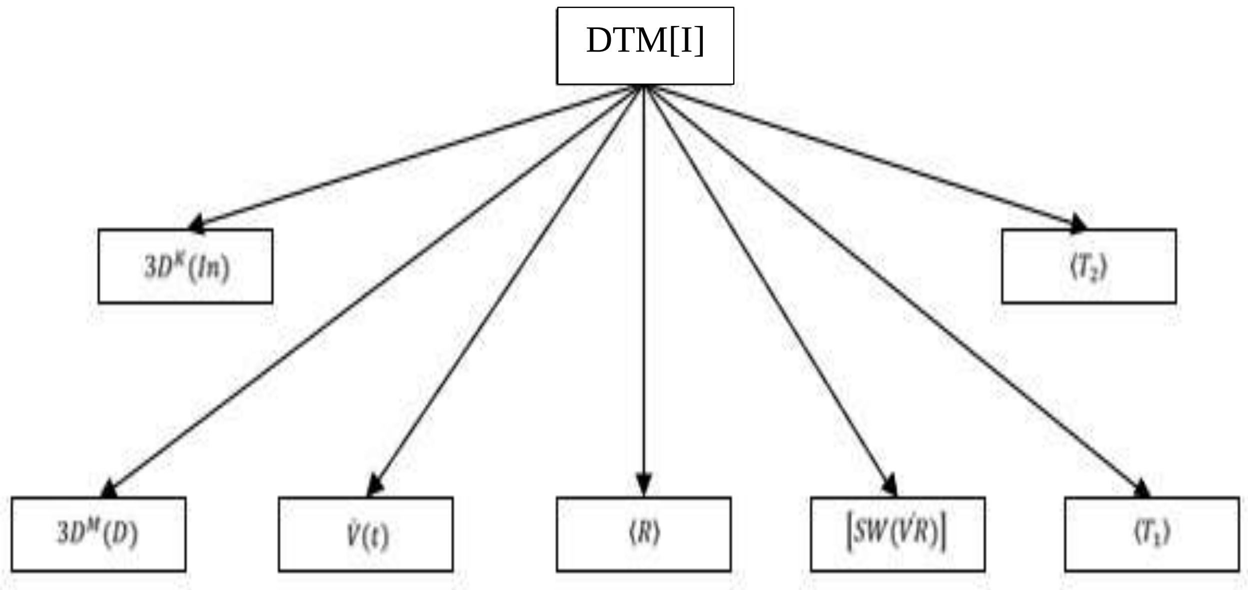


Figure 45 - Structure of DTM {I} “Helicopter Repair Training Complex

The structure of each DTM {I} of the “Helicopter Repair Training Complex” shown in Figure 45 includes the following elements:

– $3D^K(In)$ - three-dimensional models of tools, K - the number of tools needed for repairs;

– $3D^M(D)$ - three-dimensional models of parts of a prefabricated structure or unit, M - the number of fixed parts;

– $\dot{V}(t)$ - video image of the repair process;

– $\langle R\rangle$ - technical regulations for repair of the unit (documentation);

– $[SW(\dot{V}R)]$ - software module;

– $\langle T_1\rangle$ - technical documentation (regulations) for the development of $\dot{V}R$;

– $\langle T_2\rangle$ - technical documentation for use/operation $[SW(\dot{V}R)]$.

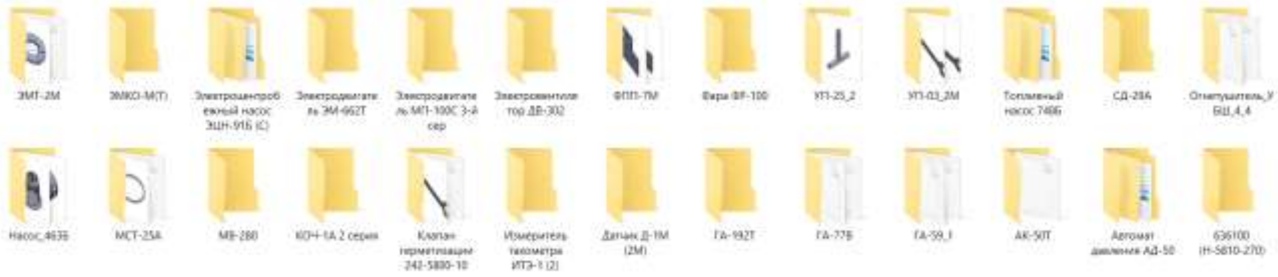


Figure 46 - Front panel of the interface of each DTM {I}

5.2 Description of the implementation of the DTM {21} - Emergency Power On Valve GA-59/1

DTM {21} - Emergency power on valve GA-59/1 - one of the important elements of helicopter, designed for automatic activation of duplicate system for power supply of hydraulic booster when pressure in hydraulic system decreases to 30±5 kgf/DM^2, as well as for disabling duplicate system when pressure in main hydraulic system rises above 35±5 kgf/DM^2 [98-99].

The valve consists of a spool, a body, a spring and a restrictor. The latter is necessary to prevent vibration of the spool in the fluid inlet connection.

Figure 47 shows the main elements of the DTM {21} - Emergency Power On Valve GA-59/1:

a) $3D^K(In)$ - three-dimensional models of tools, K - the number of tools needed for the repair;

b) $3D^M(D)$ - three-dimensional models of parts of a prefabricated structure or unit, M - the number of fixed parts;

c) $\dot{V}(t)$ - video image of the repair process;

d) $\langle R \rangle$ - technical regulations for the repair of the unit (documentation);

e) $[SW(\dot{VR})]$ - software module;

f) $\langle T_1 \rangle$ - Technical documentation (regulations) for the development of $\dot{VR}$;

g) $\langle T_2 \rangle$ - technical documentation for use/operation $[SW(\dot{VR})]$.

Figure 47 - Main element panel of the DTM {21} - Emergency power on valve GA-59/1

Conclusions of the fifth section

By order of JSC “Aircraft Repair Plant #405” a training complex “Repair of helicopter equipment” was developed, which includes 25 digital subject to overhaul, current and local repair models of helicopter aggregates. Each DOM was developed taking into account all types of provisions and according to the conceptual approach described in the thesis.

The complex is a relational database [86-89, 100-101], which is based on scientific-theoretical provisions of relational algebra: tables, relations, rows, columns, primary key, relational algebra, etc.

Describes the implementation of the DTM {21} - Emergency Power On Valve GA-59/1, which is one of the important elements of the Mi-8 helicopter.

CONCLUSION

The overall result of the work is the further development of modeling theory for digitalization of productions and increasing the level of theoretical knowledge and practical competencies of students to repair not only helicopter equipment, but also aviation in general.

In solving the problems of the study, the following results were obtained.

1. the analysis has shown that at the enterprises implementing the process of helicopter equipment repair, despite the compliance with technological quality standards, problems have been established, which require the development and implementation of scientific-theoretical foundations for modernization and improvement of technological processes. It is necessary to create methods and technologies of digitalization and automation to optimize all stages of the production cycle, improve workplace safety, form a database of repaired objects and parts to calculate costs and forecast labor and financial resources. At the same time, the main factor of importance of digitalization of helicopter repair process is qualitative improvement of training by assigning high theoretical knowledge and practical competences with minimum financial expenses and maximum self-training, as well as intensification of mental activity based on time resources distribution and professional dialogue.

These problems are solved strictly through the use of computer-based learning technologies based on 3D modeling and VR-virtual reality. These innovative solutions create a digital environment in which students can intuitively interact in real time - close to realistic three-dimensional graphics. Currently, there are no aviation production facilities in Kazakhstan that use advanced virtual reality technologies.

The conceptual apparatus was developed and the areas of application of educational technologies in the aviation industry, as well as areas of training for installation and repair specialists were determined. The model and description of helicopter repair technological process operations, stages of VR-virtual reality application development are developed.

2. As a result of a critical analysis of digitalization tools and computer learning technologies, a new conceptual approach to the classification of digital models and at the conceptual level proposed a new fourth type of model, forming realistic objects or processes based on 3D-modeling technology, VR-virtual reality and artificial intelligence, in which dynamic effects and their responses are transferred to the person through his perceptual organs - feelings.

The structural scheme of training digital models of the DM-4 in the repair of helicopters has been developed.

The characteristic scientific-theoretical support of DTM of the helicopter repair process is proposed, which confirms the systematic and methodological approach to the proposed digitalization of production and improving the quality of training with the assignment of practical competencies at a high level.

Mathematical support of the DTM is presented in the form of a mathematical model, in which from the input data of parametric and functional nature at the output is formed software application VR-virtual reality in the form of a complex function. Thanks to this software it is established that the effectiveness of the application of the DTM for the repair of helicopter equipment is confirmed by the compliance with the requirements: universality, accuracy, adequacy and efficiency, completeness, computability, modularity, robustness, clarity, etc.

Algorithmic support is a step-by-step text and graphical representation of development and functioning of DTM of helicopter repair processes. The peculiarity of this type of software is that it takes into account expert recommendations of industry specialists and placement of information in databases of 3D-models and VR-virtual reality applications. This will significantly increase the level of digitalization and automation of technological processes.

Information and production support is intended for the optimal distribution of infocommunication and technological resources of the production cycle to ensure the effective functioning of the DTM. This type of support includes the development of VR-virtual reality applications in strict accordance with reality and conducting classes for trainees and specialists of enterprises. Thanks to this provision, the advantages of DTM clearly stand out: self-learning, database build-up, and, most importantly, applicability in other industries and in transport.

The hardware and software of the DTM include a selection of modern technical means for high-performance and high-efficiency implementation and operation. The structure includes elements built on technologies in radio electronics and telecommunications, programming, visualization, artificial intelligence, psychology, and pedagogy. All hardware elements and software selected as a result of critical analysis are fully integrated with each other and applicable to the implementation of DTM for helicopter repair.

3. Developed the support of the DTM, associated with the development of a method and algorithm for calculating the assessment of practical competencies of students in the repair of aircraft equipment in VR - virtual reality environment. This type of provision determines both the level of complexity of the developed scenarios and the assessment of actions during the simulation. The calculation method is applicable to different types of training simulations: police, medical, fire or production simulations.

The developed algorithm allows to use it in VR-simulations of other life-threatening situations. It can be implemented in training courses in the field of actions in hazardous or contaminated areas. The mathematical basis of the algorithm makes it easy to adapt the training to the needs of complex situations, including emergency situations for fire teams and police emergency response squads. In air transport, such situations involve accidents and incidents. The use of an algorithm that evaluates trainee behavior under certain conditions in virtual reality training can allow for training without the presence of instructors and trainers.

The development of this provision is related to further research on the development of new scenarios with different levels of complexity of events in which civil aviation personnel may be involved.

4. The software and methodological support, which is a set of documentation and procedures for the implementation of DTM processes with the use of effective software applications and training and methodological complexes, is proposed.

The result of this type of software module VR-virtual reality, technical documentation - regulations for the development and use / exploitation of applications.

Tools for the development of software modules, including mathematical and algorithmic support of the helicopter repair center, are used software tools: *Solid Works, Blender 3D and Unreal Engine 4.*

Both technical documentations are complex structures, including step-by-step and step-by-step implementation with illustrative examples. At all stages, experts must be involved - specialists to ensure that the results of the software correspond to the real helicopter repair process.

Software and methodological support meets the high requirements for innovation, efficiency, structure and integrity, etc. But the main feature is the simultaneous impact of graphic, audio and video information on students, which is relevant to improve the quality and effectiveness of learning.

On the basis of this software is created educational and teaching material with the possibility of updating, adapting, interactive learning and formation of databases of 3D models and VR-applications of virtual reality.

5. By order of JSC “Aircraft Repair Plant #405” a training complex “Repair of helicopter equipment” was developed, which includes 25 digital subject to overhaul, current and local repair models of helicopter aggregates. Each DOM was developed taking into account all types of provisions and according to the conceptual approach described in the thesis.

The complex is a relational database, based on the scientific and theoretical principles of relational algebra: tables, relationships, rows, columns, primary key, relational algebra, etc.

Describes the implementation of the DTM {21} - Emergency Power On Valve GA-59/1, which is one of the important elements of the helicopter.

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ANNEX A

Implementation Report

УТВЕРЖДАЮ
Директор
ТОО «ST Integrator Company»
_________ Иманалиев Н.Н.
«21»июня 2022 г.

АКТ

о внедрении результатов диссертационной работы
Пирманова Ильдара Ануарбековича

Комиссия в составе:
Председатель Иманалиев Н.Н., директор
Члены комиссии:
Янгиров И.Р., технический директор
Шакиров Д.Х., главный инженер
Кадурин И.С., начальник отдела технических решений
составили настоящий акт о том, что результаты диссертационной работы Пирманова И.А. **«Разработка и внедрение цифровой модели технологического процесса ремонта вертолетной техники»**, представленной на соискание ученой степени доктора философии (PhD) по специальности «Авиационная техника и технологии» АО «Академия гражданской авиации», внедрены в технологический процесс производственный деятельности **ТОО «ST Integrator Company»** при разработке и внедрении программных VR-приложений объектов и процессов в машиностроении и на транспорта.

Объектами внедрения являются:
1) Методика разработки цифровых моделей технологических процессов;
2) Математическое, алгоритмическое и аппаратно-программное обеспечение цифровых моделей;
3) Рекомендации по внедрению в технологические процессы.

Оценка эффективности внедрения – высокая, поскольку существенно повышается качество разработки, проектирования и внедрения программных приложений на основе VR-технологий, сокращаются затраты на проведение сервисных работ и обучение обслуживающего персонала, повышается уровень автоматизации технологических процессов.

Председатель комиссии: _________ Иманалиев Н.Н.

Члены комиссии: _________ Янгиров И.Р.

_________ Шакиров Д.Х.

_________ Кадурин И.С.

ANNEX B

Certificate