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Approaches to the Detection of Deepfake in the Financial Organization's Activities

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Abstract— In recent years, significant progress has been observed as content generated using AI technologies. In addition, tools regularly appear with which scammers can create a realistic fake content. Deepfake detection methods are currently actively used in the activities of financial organizations. With their help, a division of financial organizations responsible for IT Security identify cases of fraud, protect customers and ensure the safety of digital transactions. To generate deepfake, multimodal models are used to form fake dynamic video images with sound. The work investigates generative models in the Face Synthesis task, as well as methods for detecting deepfakes created using models of this class. The analysis of the datasets used to detect deepfakes is given. The results of computer modeling confirmed the performance of the proposed approaches.

Keywords— Artificial intelligence, deep learning, deepfakes, deepfakes detection, cybersecurity, social engineering, deepfakes attacks, fintech security

I. INTRODUCTION

The term deepfake originates from the combination of "Deep Learning" and "Fake" and refers to realistic multimedia content generated using deep learning techniques. The term gained prominence after a Reddit user named "deepfakes" in late 2017 employed deep learning methods to swap one person's face with another's in pornographic videos, creating highly realistic fake videos [1].

According to the 2024 Digital Economy Report published by the United Nations Conference on Trade and Development (UNCTAD), the number of electronic devices per capita worldwide increased from 2.4 to 3.6 by 2023 [2]. North America led this trend, with an average of 13.4 devices per person. This surge in device availability reflects not only the growing number of people owning at least one device but also the increasing number of devices per individual—a trend expected to continue. Over the past decades, numerous popular online platforms (e.g., social networks, forums, and messengers) have emerged, enabling users to share multimedia content with a broad audience. Due to these two factors, the average user is exposed to an ever-growing volume of information, including misinformation. Recent advancements in deep learning have made it possible to synthesize highly realistic deepfake content, further exacerbating trust issues in online information.

New breakthroughs in generative content creation have not only been implemented in software but also equipped with user-friendly interfaces, allowing even non-technical users to generate deepfakes effortlessly. Naturally, this has led to an exponential increase in deepfake content across digital media. Cybercriminals have exploited deepfakes for financial gain—for instance, in 2024, a Hong Kong finance worker was tricked into transferring \$25 million after a video

call with deepfake imposters posing as company executives [3].

Synthetic content poses risks not only to individuals but also to organizational security. A 2022 Security Magazine study revealed that 46% of organizations faced fraud involving synthetic identities [4]. Tariq et al. demonstrated vulnerabilities in Microsoft, Amazon, and Naver APIs against deepfake-based attacks [5]. Another study by Godwill Chimamiwa confirms that AI is being weaponized by cybercriminals to craft sophisticated attacks, including social engineering tactics enhanced by deepfakes [6]. According to Cybersecurity Ventures, global losses from cybercrime are projected to reach \$10.5 trillion annually by 2025 [7]. To mitigate these risks, organizations must develop and enhance solutions for detecting synthetically generated content.

The remainder of this paper is structured as follows: Section 2 outlines the problem statement and evaluation metrics, Section 3 explores deepfake variations and generative models used in their creation, and Section 4 reviews detection methods and existing datasets for tackling this challenge.

II. PROBLEM STATEMENT

The advancement of deepfake technology poses a significant threat to financial institutions, particularly in identity verification processes such as customer onboarding, transaction authorization, and compliance monitoring. The ability to generate high-quality synthetic content and manipulate media in real-time undermines the integrity of Know Your Customer (KYC), Anti-Money Laundering (AML) protocols, and real-time transaction verification systems. According to Nguyen et al., traditional verification systems perform poorly in detecting deepfakes [8]. This finding is corroborated by a successful deepfake spoofing attack on China's facial recognition tax system, resulting in \$76.2 million in losses [9]. To mitigate such risks, organizations must develop advanced solutions for detecting synthetic content.

Algorithm Requirements and Evaluation Metrics

Let C_i – input data, $C_i \in \{\text{image, video, audio}\}$, x_i – analyzed object, $x_i \in \{\text{image, video, audio}\}$, which may have been altered by a generative network G_θ , i.e. $x_i = G_\theta(C_i)$. If unaltered, $x_i = C_i$. The goal is to design an algorithm f that classifies x_i with a label $y_i \in \{\text{real, deepfake}\}$.

Thus, f solves a binary classification task. Standard evaluation metrics include: Accuracy, Precision, Recall, F1-score, ROC-AUC.

III. DEEPPAKE CREATION

A. Types of Deepfakes

Modern deepfake technologies can be categorized into six primary types, each with distinct technical characteristics and applications [10]:

- *Face Swapping*. Replaces a source face with a target face, enabling fabricated scenarios (e.g., fake news, impersonation in video calls).
- *Lip Syncing*. Alters lip movements to match arbitrary audio, often used in dubbing or to distort public speeches.
- *Puppeteering*. Manipulates facial expressions, gestures, and body language (e.g., for cinematic effects or malicious edits).
- *Face Synthesis*. Generates photorealistic faces of non-existent individuals for fake social media profiles or disinformation.
- *Facial Attribute Manipulation*. Modifies features (e.g., skin tone, freckles) to reinforce stereotypes or discredit individuals.
- *Audio Deepfakes*. Clones voices or alters existing recordings, threatening voice biometric systems and legal evidence.

B. Generative Architectures for Image-Based Deepfakes

Face synthesis and replacement remain key challenges in generative AI, with various neural network architectures being employed to address them. Let us examine the different families of generative model architectures that can be used to create deepfakes:

- *Autoregressive Models (PixelCNN)* [11] generate images pixel-by-pixel. The core concept involves predicting the probability of each pixel value $x_i \in [0,255]$ based on preceding pixels. This approach represents early experiments in generative AI, where image synthesis is computationally intensive while producing suboptimal quality results.
- *Variational Autoencoders (VAE)* [12,13] learn to compress images into latent vector representations and subsequently reconstruct them. Specifically, VAEs model data distributions in latent space, enabling both data compression and novel sample generation. Key advantages include: rapid generation of new samples, effective latent space interpolation, high interpretability. Notable limitations comprise: blurred output images, difficulties modeling complex distributions
- *Generative Adversarial Networks (GANs)* [14] consist of two neural networks - a generator (G) and discriminator (D). The generator creates synthetic samples, while the discriminator acts as a binary classifier determining whether input samples originate from training data or generator G. Training objective for G is to maximize discriminator's error rate, establishing a minmax game between both components. Advantages include: high-quality output (particularly in modern architectures), rapid sample generation, architectural flexibility for diverse tasks. Key limitations: training instability, generation artifacts in early architectures, limited interpretability, substantial computational requirements.
- *Energy-Based Models (EBMs)* [15] learn to represent data probability through energy functions. Advantages include: capability to model complex distributions,

compatibility with other generative approaches, preservation of output diversity. Key limitations: computational complexity, poor performance on high-resolution image generation, convergence challenges in high-dimensional spaces.

- *Diffusion Models (DMs)* [16] implement an iterative noise removal process until obtaining target sample x_0 from the distribution. The framework incorporates:
 - Forward diffusion: Gradually corrupts input x_0 over T steps into Gaussian noise
 - Reverse diffusion: Implements neural network $p\theta(x_{t-1}|x_t)$ for iterative denoising

Advantages include: exceptional generation quality, artifact-free outputs, stable training dynamics, multimodal applicability. Key limitations: significant training costs, slow sampling speed, prompt sensitivity in text-to-image architectures.

- *Normalizing Flows (NFs)* [17] transform simple distributions (e.g., Gaussian) into complex ones through a sequence of invertible and differentiable transformations. Key advantages include: exact input reconstruction due to invertible transformations, interpretable latent space, compatibility with hybrid models. Key limitations: suboptimal generation quality (particularly for high-resolution images), computational complexity, challenges in image stylization.

Currently, GANs, DMs, and their combinations with other approaches represent the primary tools for deepfake creation. It's worth noting the remarkable architectural diversity within each generative model family. For instance, a well-known GitHub repository documents over 500 GAN variants [18] developed between 2014-2018.

C. Audio Deepfakes

Современные Modern speech synthesis and voice cloning technologies have achieved near-indistinguishable realism from genuine human voices. Audio deepfakes can accurately replicate:

- Vocal timbre and intonation patterns
- Regional accents and emotional inflections
- Natural speech rhythms (including pauses and breathing)

The combination of audio-visual deepfakes poses particularly severe threats. The most prevalent audio deepfake generation techniques employ: neural vocoders (e.g., WaveNet), GAN-based architectures, Sequence-to-sequence models [10,19].

D. Deepfake Creation Services

As discussed in Section I, many challenges associated with deepfake technology stem from its increasing accessibility. Cutting-edge advancements in synthetic content creation have been implemented in user-friendly software, enabling even non-technical PC users to produce high-quality forgeries. Currently, numerous services exist for generating various types of deepfakes, with some popular solutions listed in Table I.

TABLE I. DEEPPFAKE GENERATION SERVICES

Service	Decision	Deepfake type
crazytalk	Commercial web app	Lip Syncing
dynalips	Commercial web app	Lip Syncing
Adobe Premiere	Commercial desktop software	Attribute Manipulation
Rosebud	Commercial web app	Facial Attribute Manipulation
ZAO	Mobile application	Face Swapping
REFACE	Mobile application	Face Swapping
Reflect	Mobile application	Face Swapping
FakeApp	Desktop solution	Face Swapping
FaceSwap	Open-source solution	Face Swapping
FaceSwapGAN	Open-source solution	Face Swapping
Faceswapweb	Commercial web app	Face Swapping
DALL-E 3	Commercial web app	Face Generation
Stable Diffusion	Open-source solution	Face Generation
Picsart AI	Commercial mobile/web app	Face Generation

IV. DEEPPFAKE DETECTION

A. Public Datasets for Deepfake Detection

The advancement of deepfake detection methods directly depends on the quality and diversity of the data used to train and test algorithms. In recent years, research groups and technology companies have released several public datasets containing both authentic and synthetic images, videos, and audio recordings. These published datasets enable the testing and refinement of approaches for detecting synthetically generated content. Some popular datasets are listed in Table II. The datasets vary significantly across multiple parameters:

- *Dataset size*: Early datasets contained a few thousand synthetic images, while modern ones include over a million.
- *Recording environment and conditions*: Studio recordings under controlled lighting vs. varied backgrounds and natural lighting.
- *Deepfake type*: Different deepfake categories, as described in Section III (Deepfake Creation).
- *Ethnicity*: Predominance of Caucasian or Asian faces.
- *Content quality* variations.
- *Generative models* used to create the deepfakes.

TABLE II. DEEPPFAKE DETECTION DATASET

Name	Real/Fake Data	Year	Data Type
UADFV [20]	49/49	2018	Video
DeepfakeTIMIT [21]	320/640	2018	Video
DFFD [22]	1000/3000	2019	Video
Celeb-DF [23]	590/5639	2019	Video
DFDC [24]	23,564/104,500	2019	Video
FaceForensic++ [25]	1000/5000	2019	Video
FFIW-10K [26]	10,000/10,000	2019	Video
DeeperForensics-1.0[27]	50,000/10,000	2020	Video
Wild-Deepfake [28]	3805/3509	2021	Video
ForgeryNet [29]	99,630/121,617	2021	Video
KoDF [30]	62,166/175,776	2021	Video
DF3 [31]	0/46,476	2021	Video
DF-Platter [32]	764/132,496	2023	Video
FakeAVCeleb [33]	500/19,500	2021	Audio
FFHQ [34]	0/7000	2019	Image
iFakeFaceDB [35]	0/87,000	2020	Image
100k Faces [36]	0/100,000	2021	Image

Name	Real/Fake Data	Year	Data Type
DFGC [37]	1000/N × 1000	2021	Image
ForgeryNet [29]	1,438,201/1,457,861	2021	Image
DeepFakeFace [38]	30,000/90,000	2023	Image
DiffusionDeepfake [39]	94,120/24,794	2024	Image
DF40 [40]	1,000,000 fake	2024	Image

B. Deepfake Detection Competitions

Deepfake detection competitions, such as the Deepfake Detection Challenge (DFDC), DeepForensics Challenge, Audio Deepfake Detection, Deepfake Game Competition, and Face Forgery Analysis Challenge, play a crucial role in advancing methods to combat synthetic content. These initiatives bring together researchers and developers by providing standardized datasets and clear evaluation criteria for testing algorithms. The importance of such competitions lies in several aspects:

- Open competitions with monetary prizes motivate research teams to develop high-quality solutions.
- Unified evaluation metrics and datasets enable objective comparison of different approaches.
- Many solutions are published as papers or open-sourced, allowing subsequent researchers to build upon these ideas.
- The best-performing solutions are often integrated into content verification tools.

C. Deepfake Detection Methods

Deep feature-based methods rely on analyzing latent data representations extracted by convolutional neural networks (CNNs) or transformers. These approaches are based on the premise that generative models leave unique patterns in synthetic images and videos—imperceptible to the human eye but detectable by neural networks. For example, pre-trained models like XceptionNet [41] and EfficientNet [42], trained on large datasets, can capture microscopic distortions in skin textures, anomalies in reflections, or unnatural color gradients. However, numerous studies indicate that relying solely on deep features does not yield impressive results [43–45].

Frequency-domain analysis (using FFT, DCT, or wavelets) has shown promising results for detecting GAN-generated deepfakes [44]. However, these methods perform significantly worse when applied to synthetic content created with Diffusion Models (DM).

For face-swapping detection, a range of approaches focuses on identifying inconsistencies between the face and its surroundings (e.g., lighting discrepancies and unnatural eye reflections) [46–48]. In video content, biological signal analysis (e.g., blinking patterns) is employed, as these are difficult for deepfakes to replicate accurately [49].

In their work, Nataraj L. et al. proposed [50] computing co-occurrence matrices across the three color channels and using them to train a CNN. This approach demonstrated promising results for detecting deepfakes generated by certain GAN-based models. Guarnera L. et al. introduced a method to extract convolutional traces from images using the Expectation-Maximization (EM) algorithm, which also proved effective against GAN-generated deepfakes [51].

To analyze deepfake attacks targeting online services (e.g., internet banking or cryptocurrency exchanges), the authors of [52] developed a multimodal model that considers not only video and audio content but also user behavioral

patterns (keystroke dynamics, mouse movements, and micro-expressions). This approach achieved impressive accuracy even against state-of-the-art deepfake attacks.

V. CONCLUSIONS

This paper presents a series of methods for detecting deepfakes. Each method has its own advantages and disadvantages, so combining different approaches is recommended to create a high-quality solution. The extremely rapid development of generative algorithms contributes to the creation of increasingly realistic deepfakes, which necessitates retesting the aforementioned detection techniques. Further research is planned in the following directions: searching for new techniques to detect synthetically generated multimedia content, testing the applicability of existing deepfake detection methods to multimedia content created using the latest generative algorithms, and creating a custom dataset.

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Integration of Quality Management and Production Organization Based on Digital Technologies

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Abstract—The development of modern industry leads to increased requirements for the quality of products and their production processes. This is especially true in high-tech industries such as precision engineering, electronics, instrumentation, aircraft manufacturing, etc. Improving the quality of products and production processes is achieved in various ways. Quality assurance and management issues are based on modern quality management systems (QMS). The quality of processes is ensured within the framework of information systems of the production organization (ERP, MES, etc.). In recent years, digital technologies have been widely developed in relation to the topic under study – artificial intelligence, big data, blockchain, digital twins, etc. The concepts of Industry 4.0 and Quality 4.0 began to be used. In this paper, possible integrated methods of product and process quality management based on digital technologies are considered. The options for integrating the basic principles of quality management, the process approach to the organization of production and digital technologies are shown. The combination of the considered approaches can be considered as quality management 5.0.

Keywords— *quality management, artificial intelligence, big data, blockchain, digital twins, digital technologies,*

I. INTRODUCTION

Modern manufacturing can be competitive while ensuring product quality and minimizing costs. One of the ways to reduce production costs is the rational organization of production. The quality management system (QMS) guarantees the receipt of the specified quality parameters. QMS is usually created on a ready-made basis and adapts to existing functional, technological, organizational and qualification realities. In this situation, the end result is not always optimal. The widespread digital transformation makes it possible to simultaneously improve the organizational structure of production and QMS based on digital technologies (DT). Therefore, it seems logical to approach the change of production processes while optimizing the organizational structure, QMS and DT.

Quality management in the modern economy is a priority tool for increasing the competitiveness of products, services, their creation processes and enterprises in general. The combination of various quality management methods has led to the creation of modern quality systems.

The American Society for Quality Control presents an overview of the concept [1], in which the evolution of "Quality 4.0" is considered as a parallel with the development of industry:

Quality 1.0. Until 1890, the work was not mechanized and was carried out mainly manually, there was control and simple measurements to ensure quality.

Quality 2.0. From 1890 to 1940, mechanization increased scale, productivity, and production volumes. Standards for various types of products were introduced, metrological support was created. Along with Western countries, the Soviet Union played a major role in industrialization by implementing relevant government programs. Progressive scientific methods of quality assurance have emerged.

Quality 3.0 — from 1940 to 1995, the concepts of continuous improvement and universal quality management of TQM appeared. The focus has shifted from control to quality management, from product quality to process quality. International quality management standards of the ISO 9000 series have been developed based on best practices.

Quality 4.0 — since 1995, artificial intelligence (AI), virtual reality (VR), augmented reality (AR), machine learning (ML), digital twin (DT), blockchain and other digital technologies have been used in processes.

In recent years, people have started talking about Industry 5.0, which differs from Industry 4.0 with a greater focus on humans and the environment [2-4]. The approach to quality is changing accordingly [5-8].

In the modern economy, quality control has transformed into a comprehensive system based on continuous data analysis. Thanks to the development of digital technologies, primarily Big Data, enterprises have been able not only to detect deviations, but also to predict them, identify hidden patterns and prevent defects before they occur. This has become possible thanks to the introduction of modern data analysis methods, including predictive analytics, which allow processing huge amounts of information in real time. Modern real-time data analysis systems have revolutionized approaches to quality management, turning it from a periodic control event into a continuous dynamic process. These technologies make it possible not only to record deviations that have already occurred, but to instantly respond to the slightest changes in production parameters, preventing the appearance of defects at the earliest stage. Unlike traditional systems, where data analysis could take hours or even days, modern real-time platforms process information flows with tremendous speed, which is especially critical for high-speed production lines and processes with tight technological tolerances.

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II. DIGITAL TECHNOLOGIES IN MODERN PRODUCTION

A. *Selecting a Template*

Let's look at some digital technologies used to ensure quality or potentially being such.

Big Data is a modern information management tool that transforms approaches to data analysis in various fields of activity, including quality management. Big Data represents very large amounts of heterogeneous digital data that cannot be efficiently processed using traditional methods. In general, it is a set of technologies, methods and tools for collecting, storing, processing and analyzing such information arrays. Modern Big Data technologies have revolutionized approaches to quality management, making it possible to move from correcting inconsistencies to predicting and preventing them through preventive actions.

The basis for predicting defects is made up of complex machine learning algorithms that process accumulated data on production processes, equipment operation, and detected inconsistencies. These systems reveal subtle relationships between hundreds of parameters that are not obvious to ordinary human analysis, even with high qualifications. Such systems include powerful streaming data processors capable of analyzing information directly at the time of its receipt, without prior accumulation and batch processing. In industry and manufacturing, Big Data plays a key role in improving product quality, optimizing production processes, and reducing costs. One of the main applications of big data is Predictive Maintenance. Sensors and IoT (The Internet of Things) devices installed on the equipment collect data on vibrations, temperature, load, and other machine operation parameters. By analyzing this data using machine learning algorithms, companies can predict possible breakdowns and perform maintenance before critical failures occur, which significantly reduces downtime and increases production reliability. In this case, it is possible to identify a faulty part or assembly without disassembling the entire unit. For example, you can determine which bearing inside the machine is already on the verge of failure and needs urgent replacement. Big Data technologies also contribute to cost reduction by minimizing the human factor. In addition, the integration of quality control systems with ERP and MES systems of enterprises allows you to quickly adjust production processes based on acceptance data, preventing the release of nonconforming products and related financial losses.

The introduction of Big Data technologies into control systems may face significant difficulties in integrating with existing information systems and production processes at enterprises. The main problem is that most industrial enterprises have an IT (Information technology) infrastructure that has been established for years, consisting of heterogeneous, often outdated production management systems, manufacturing execution systems (MES), enterprise resource planning (ERP) systems and specialized quality control software. These systems were developed at different times and use different data standards and information exchange protocols, which creates serious obstacles to their integration with modern Big Data platforms. This problem is especially acute in large industrial enterprises with a long history, where systems of different generations often operate simultaneously, from completely outdated solutions based on legacy code (legacy systems) to modern cloud services.

The Internet of Things, combined with industrial Internet technologies, can dramatically improve the quality of

products and production processes, where thousands of sensors generate continuous streams of data on equipment status and product parameters. Sensors installed on the equipment continuously collect information about production parameters such as temperature, pressure, vibration, and operating speed of machines and aggregates. This is of particular value for a real-time system. Modern streaming analytics algorithms are able to identify complex correlations between various parameters that would be invisible in an isolated analysis. An important advantage of real-time systems is their ability to predictive analytics - predicting potential quality problems before they actually occur. By analyzing the dynamics of parameter changes, these systems can calculate possible process implementation options and predict the moment when the values will exceed acceptable limits. The quality of forecasts directly depends on the completeness and accuracy of the input data, which requires careful configuration of information collection systems. In addition, it is necessary to overcome the psychological barrier of the staff, who traditionally relied on their own experience rather than on the recommendations of algorithms. Successful companies solve these problems through the creation of hybrid systems where decisions are made jointly by humans and artificial intelligence.

Digital twins (DT). Modern enterprises are implementing [9] digital counterparts of production processes and products, and sometimes the entire enterprise. These are virtual models that "live" in parallel with real processes and allow you to:

- analyze system behavior in real time;
- quickly test changes without risk to real production;
- evaluate the impact of technological parameters on product quality.

III. ORGANIZATION OF PRODUCTION

Technology, equipment, and production organization play an important role in obtaining a high-quality product or service. The issues of choosing the optimal technology and equipment for its implementation go beyond the scope of this work and are considered in specialized publications.

The organization of production for the efficient and rational operation of the enterprise should include:

- the organization of the main production process from the timely receipt of materials and blanks of the required range and volume to the final inspection of finished products;
- means of production – the necessary equipment that best corresponds to the parameters of the processed products;
- tool manufacturing, ensuring the availability of the most suitable and serviceable tools and technological equipment at the workplace;
- repair facilities for timely maintenance of equipment;
- transport, energy and storage facilities;
- means and methods of technical and technological preparation of production, including the availability of design and technological documentation;
- information support services – hardware and software support for all business processes;

- ensuring the quality of work by having an employee at the workplace who is most suitable for performing the required task.

All these elements need to be coordinated in time, space and resources so that they work as a single mechanism.

And one of the main elements of obtaining competitive products is effective management, including the availability of modern QMS [10]. The concept of a modern QMS means not only an ISO 9001 certified quality system, but also its integration with modern information technologies considered in this paper.

IV. THE MAIN COMPONENTS OF THE DIGITAL QUALITY MANAGEMENT SYSTEM

A digital QMS can be based on a modular architecture in which each element enhances the others and provides a single quality chain from obtaining process data to automatic response. Some of the components of the DQMS are listed below:

Data Collection Infrastructure. Sensors, cameras, production controllers (PLC), IoT devices record parameters in real time: temperature, pressure, vibration, humidity, performance, deviations, etc. Digital database and storage. All data is transferred to a centralized storage (on-premise or cloud), where it is standardized, structured and made available for analysis.

Predictive Analysis module. Based on machine learning, the system learns to identify information indicating potential inconsistencies or defects. This allows you to take action before the deviation affects the process and its results.

Feedback mechanisms. Automatic change of production line parameters or signal to the operator. Automatic changes can occur according to established algorithms or be determined by artificial intelligence.

The transition to a digital quality management system allows organizations to implement Continuous Improvement in real time; reduce the time required to identify and eliminate defects; and flexibly respond to changes in the external environment.

A. Real-time analytics: concept and principles

One of the key characteristics of a digital quality management system (QMS) is the ability not only to collect and store data, but also to analyze it in real time. Unlike the traditional approach, where data is processed after the fact, real-time analytics allows you to make decisions instantly - in the process of the production or management action itself.

Real-time analytics [11-12] is the process of collecting, processing, and interpreting data immediately after it is received, for the purpose of rapid decision-making or automatic response. It is characterized by high processing speed, continuity, and minimal delay between the event and the system's response.

In other words, real-time analytics is streaming data processing that provides visibility of current processes and allows you to quickly manage deviations and changes.

Thus, real-time analytics eliminates the "information gap" between the moment of the event and the moment of reaction, which is especially critical for quality management.

To implement real-time analytics in a digital quality management system, it is necessary to adhere to several technological and methodological principles:

Data streaming architecture. Data is received continuously, in the form of streams, and not in batches.

Instant data analytics and filtering. The system automatically recognizes anomalies, groups values, calculates averages, deviations, and compares them with acceptable standards.

Trigger response mechanisms. Exceeding the thresholds or triggering a condition leads to the appropriate action: notifying personnel, automatically stopping equipment, or launching a correction algorithm.

BI (Business Intelligence) [13] integration and visualization. The data is displayed in live dashboards, which allow you to see the current state of equipment, processes, and product quality.

Minimizing latency. The architecture should be optimized according to the principle of "low latency", that is, all stages (transmission, processing, reaction) take minimal time.

B. Technologies for analytics in the digital quality management system

Effective implementation of real-time analytics within a digital quality management system is impossible without the use of modern digital solutions. They provide the collection, processing, storage, visualization, and interpretation of data coming from production sites, sensors, customer systems, and logistics chains. Modern digital QMS (DQMS) are a complex integrated structure that involves both hardware and software components. Each technology fulfills its role in the overall quality assurance and control system, creating the basis for rapid and informed decision-making.

IoT and sensors. The Internet of Things (IoT) is a key component of the digital quality environment. Sensors installed on production equipment, packaging lines, shipping containers, and even indoors collect all possible data about processes and their results. All this data is fed into the system in real time and serves as the basis for analytics.

Stream processing. Streaming platforms are required to process continuously incoming data. They provide real-time information transformation and processing. Examples include Apache Kafka [14], a highly loaded platform for transmitting data streams; Apache Flink, Apache Spark Streaming, platforms for distributed streaming with the ability to perform real-time calculations; MQTT, RabbitMQ, messaging systems often used in IoT environments.

Artificial intelligence, machine learning, and predictive analytics (AI/ML) technologies are actively used in DQMS. Further development of this area is associated with the integration of predictive analytics systems into end-to-end digital quality management platforms, where data from suppliers, production lines and customer reviews are combined into a single analytical environment. This will make it possible to create comprehensive quality models that take into account the entire product lifecycle, from development to disposal. Thus, machine learning transforms the very philosophy of quality management, making it more accurate, predictable, and cost-effective. Realizing the full potential of Big Data in quality management requires overcoming significant challenges, from the technical difficulties of integration with existing systems to issues of protecting confidential information, the need for significant investments, and the training of qualified personnel. This is especially true for traditional industries, where the digital

transformation of processes is faced with the inertia of established approaches and infrastructural constraints.

In the modern digital economy, Digital Twins technologies play a key role in quality management, allowing the creation of dynamic virtual copies of physical objects, processes or systems. Unlike static 3D models, digital twins reflect the state of their prototypes in real time through continuous data exchange, which opens up new possibilities for forecasting and quality control at all stages of the product lifecycle.

The basis of the work of digital twins is the integration of data from IoT sensors, production systems and ERP platforms. This allows you to identify problems before defects occur. In the aerospace industry, virtual copies of aircraft components simulate their behavior in various conditions, identifying weaknesses at the design stage.

The effectiveness of Digital Twins increases when integrated with artificial intelligence and augmented reality (AR). AI allows DT not only to monitor the condition of objects, but also to offer solutions to improve quality. AR technologies help to visualize problems and ways to fix them directly in production.

The introduction of digital twins requires solving a number of tasks: creating a reliable infrastructure for data processing, developing accurate mathematical models, and ensuring cybersecurity. The prospects of technology are related to the formation of complex ecosystems, where the twins of individual components are combined into a single production chain model. This will allow analyzing quality at the system level, taking into account the interaction of various factors. In the future, "quality twins" may appear – intelligent systems that independently change the parameters of the production process in real time and optimize processes.

V. CONCLUSIONS

The modern digital economy requires companies to be highly adaptable and quick to respond to changes [15-18]. In such conditions, traditional quality management methods based on strict standards and long control cycles often prove to be insufficiently effective. Artificial intelligence (AI), blockchain, Big Data, digital twins, augmented reality (AR) and virtual reality (VR), as well as additive manufacturing form innovative technologies in Industry 5.0 that promote human-machine interaction and adaptive manufacturing. Industry 5.0 is not just a technological evolution, but a global transformation that is changing the way organizations design, manufacture, and interact with the environment, creating a more efficient and sustainable industrial future.

Within the framework of Industry 5.0, employees work closely with intelligent machines, distributing tasks and responsibilities among themselves. Quality 5.0 is an evolutionary continuation of existing quality assurance methodologies (TQM, Lean, Six Sigma, Quality 4.0) and adds fundamentally important elements to them: human-centricity, deep digitalization, and focus on the ESG agenda (E — environment, S — social, G — governance).

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Section 1. Quality Management

- **Integrated Management Systems for Digital Technology Enterprises**
- **Quality of Information Technologies and Systems**
- **Methods and Software/Hardware Tools for Quality Management and Control**

Information Technologies in the Development of Transport Security

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Abstract— In the context of globalized development of international transportation, information technology plays a key role in ensuring the functioning of the transport industry. The article examines the software products used by various modes of transport, identifies their existing shortcomings, presents and analyzes the sources and threats to transport security. The authors proposed an organizational and technical justification for the project of an automated information system for transport security.

Keywords—transport, security, threats, infrastructure, standards, information, technology.

I. INTRODUCTION

The Transport security is an ongoing process, as well as a system of measures aimed at protecting vehicles, passengers, cargo and infrastructure from various threats and risks that require constant attention and adaptation to changing conditions in order to create efficient, safe and sustainable transport systems around the world. With increasing automation and digitalization of transport processes, the risk of cyber attacks increases, which can paralyze infrastructure. Traffic control systems, ticket booking processes, and cargo monitoring are becoming vulnerable to hacker attacks. Therefore, it is necessary to implement modern information security systems and regularly update the software [7]. It is also important to train employees in the basics of cybersecurity and the development of strict access protocols to systems.

In the context of modern threats, transport security is one of the key areas requiring special attention, since the safety of transport and the transportation process is the most important criterion for a high level of transport services [1].

Transport safety is a key component of the stable and safe functioning of society, as it affects the economic development of the country and the social well-being of the population. The number of vehicles is increasing every year all over the world, and in this regard, the burden on infrastructure is increasing, and as a result, the topic of safety in this area is relevant and important to consider.

Transport safety issues have been reflected in the works of Russian and foreign scientists: D. Y. Glinchikov, D. V. Krepak, A. E. Cherednichenko, V. N. Azarov, B. V. Boitsov, V. P. Mayboroda, E.L. Kuzina, M.F. Guskova, A.M. Zorin, S. N. Zaikova, V. G. Voloshin, S. V. Kudryavtseva, N. N. Pestova Chebrolu, S.B., Ness L. et al.

Scientific papers explore a wide range of IT solutions designed to manage the transportation industry. Among them are: transport Management Systems (TMS), cargo movement monitoring and control systems (GPS/GNSS trackers), automated document management systems (EDI), as well as specialized platforms for route planning and optimizing vehicle loading. However, there are certain disadvantages in the application of current IT solutions. This determined the purpose of the study – the organizational and technical justification of the project of an automated information system of transport security. To achieve the goal, the following tasks are highlighted:

- to study the applied modern information technologies in the transport industry;
- to reveal the main elements of the automated information system of transport security;
- to provide an organizational and technical justification for the project of an automated information system.

Thus, the research and analysis of modern information transport technologies is an important task, the solution of which will reveal the prospects and directions for further development of IT tools in this area.

II. MODERN INFORMATION TECHNOLOGIES IN THE TRANSPORT INDUSTRY

The Russian transport system actively uses and implements modern information technologies to improve the efficiency of management and control of the transportation process, optimize cargo transportation and ensure transparency of all stages of delivery. In the context of the globalization of international trade, the use of information systems is becoming a key success factor in the organization of transportation. Information systems used in the transport industry can be classified by type of transport (Table 1). However, there are certain disadvantages in the application of current IT solutions:

- insufficient integration of systems with each other, which makes it difficult to exchange data between different participants in transportation.
- the problem of software and hardware compatibility, especially when switching to new technology platforms.

- the problem of information security and data protection, given the growing number of cyber attacks and leaks of confidential information.

TABLE I. USED IT SYSTEMS OF THE TRANSPORT INDUSTRY

Type of transport	IT systems and their applications
Railway transport.	<ul style="list-style-type: none"> - automated traffic control systems such as GID Ural VNIIZHT, ASU ST, ASOUP, etc. They allow you to plan train routes, monitor their location in real time, and manage the loading of car and container fleets. - AS ETRAN electronic document management systems, providing automation of registration of transport accompanying documents.
Road transport.	<ul style="list-style-type: none"> - fleet monitoring and management systems Wialon, Omnicomm. They provide vehicle location tracking, traffic schedule monitoring, fuel consumption, and vehicle condition. - Electronic navigation and route planning systems help optimize traffic flows and minimize fuel costs.
Sea transport	<ul style="list-style-type: none"> - Portal information systems such as the Seaport Portal. They integrate data on ship movements, cargo, terminals, and warehouse operations. It allows you to automatically process requests for a ship to enter the port, track its movement and coordinate the work of berths and warehouses.
Air transport	<ul style="list-style-type: none"> - Air Traffic Management Systems (ATM). These systems ensure flight safety and flight planning. - automated ticket booking systems (Global Distribution System GDS). They allow you to manage passenger traffic and baggage handling. - electronic data interchange (EDI) systems for interaction with other participants in the transport process.

An important aspect of ensuring transport security is the integration of modern information technologies. Transport security threats are classified according to the nature of the threat sources (Fig. 1).

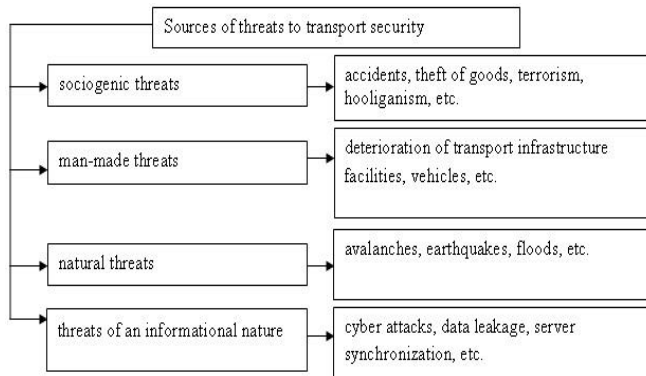


Fig. 1. Sources of threats to transport security [2]

Therefore, there is a need to develop such an automated transport security information system capable of countering various threats.

III. KEY ELEMENTS OF THE AUTOMATED INFORMATION SYSTEM OF THE TRANSPORT INDUSTRY

To So, the automated information system contains main components (Fig. 2):

- information as a subject and product of the management system;
- information technology, including information processing tools and methods;
- personnel who implement the information process using available information technologies.

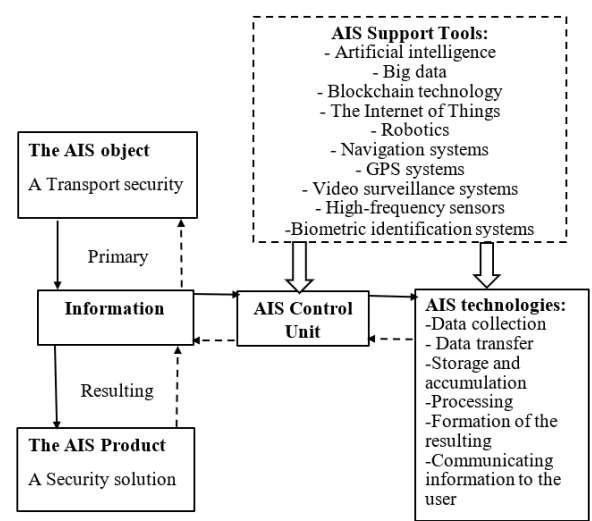


Fig. 2. Information technologies in decision-making on transport security

At the entrance to the automated information system, there is primary information about all changes occurring in the management facility (transport security). Information, as the subject of a management system, is recorded as a result of performing operational accounting functions. In an automated information system, primary information is transformed into a result-based, decision-making product of the information system. In an automated information system, part of the procedures for the formal transformation of primary information into final information is automatically performed by technical means according to predefined algorithms without direct human intervention.

However, this does not mean that an automated information system can fully function automatically. The management system staff determines the composition and structure of primary and resultant information, the procedure for collecting and registering primary information, controls its completeness and reliability, determines the procedure for converting primary information into resultant information, and monitors the progress of the transformation process.

In addition, the procedure for assessing the completeness and reliability of primary information is still poorly automated, therefore, the control of the received

informatization is also carried out by the personnel of the management system.

The most important part of the technical means of information transformation are robots and computers that perform automatic data processing based on certain algorithms and programs.

The procedures of the information process are decentralized and performed in the interactive mode of the user's work with the device, which allows a person to control the process of data transformation, promptly directing it in the right direction. This technique allows you to avoid untimely identified errors.

Thus, in modern AIS, automatically executed information process procedures are integrated with management

functions. Along with their main functions, they are directly performed by management personnel. The system uses software tools and resources aimed at the user who does not have professional computer training.

A specialist can independently automate the execution of the necessary data processing procedures, while simultaneously acting as a task planner and programmer.

IV. ORGANIZATIONAL AND TECHNICAL JUSTIFICATION FOR THE INTRODUCTION OF AN AUTOMATED INFORMATION SYSTEM FOR TRANSPORT SECURITY

The solutions as a product of the automated information system of transport security are presented in Table 2.

TABLE II. IT SOLUTIONS TO IMPROVE TRANSPORT SYSTEM SECURITY

Solution	Characteristic
Improving the technical condition of vehicles and infrastructures	Regular maintenance and repairs. Modernization and updating of equipment. Introduction of new environmental technologies. Strengthening quality control.
Optimization of traffic management	Implementation of intelligent transport systems (ITS). Development of public transport and alternative modes of transport. Construction of new roads and interchanges.
Data integration and creation of unified databases	Creation of unified information systems that allow monitoring the state of the transport system in real time and promptly responding to emerging threats.
Development of transport modeling and forecasting	Using data to predict traffic flows, identify potentially dangerous areas, and develop measures to reduce the risk of accidents.
The use of innovative materials and technologies	The use of more durable and safer materials in the production of vehicles and infrastructure, the introduction of new technologies such as unmanned vehicles and artificial intelligence systems.
Managing external factors	Forecasting and warning about dangerous weather conditions and ensuring road safety in these conditions. Strengthening infrastructure to protect against natural disasters.
Ensuring cybersecurity	Development and implementation of cyberattack protection systems and training of personnel in cybersecurity rules. Regular testing of security systems. Developing plans to respond to cyber attacks.
Improving regulation and control	Development and adoption of effective legislation. Strengthening control over compliance with the rules and the fight against corruption. Implementation of a system of fines and penalties for violations of safety rules.
Increased funding	Allocation of sufficient funds for infrastructure renovation. Purchase of new equipment. Staff training in order to improve their skills.
Improving the human factor	Staff training and advanced training. Monitoring of the health and psychophysiological condition of the staff. Promotion of safe transportation.

The safety of transport operations is influenced by many factors related to both domestic and international transportation. An important aspect is the technical condition of the transport infrastructure and rolling stock. Many problems, such as accidents and malfunctions, may be related to outdated technologies and insufficient maintenance. To solve this problem, it is necessary to invest in infrastructure modernization, the introduction of modern technologies such as automated control systems for vehicles and routes, as well as regular inspections and preventive maintenance [5].

Further development of the transport security system can be based on the use of the latest technologies, such as artificial intelligence and big data, which will significantly increase the effectiveness of security monitoring and management on various transport routes. For example, the introduction of predictive analytics systems will allow you to identify potential threats in advance and develop strategies to prevent them. These technologies can analyze huge amounts of data in real time, which will help predict possible incidents and respond to them before they occur.

Process automation provides a higher degree of control and reduces the likelihood of human error. Modern intelligent transportation systems (ITS) are capable of integrating data from various sources such as surveillance cameras, sensors, and GPS devices, providing control center operators with a complete picture of what is happening.

In addition, the introduction of advanced technologies plays an important role in ensuring transport security. Modern data monitoring and analysis systems provide a higher degree of predictability and response to potential threats. The use of artificial intelligence and machine learning makes it possible to process huge amounts of data, identify anomalies and potential threats in real time. This helps not only to prevent incidents, but also to respond promptly to them, minimizing the consequences [10].

The introduction of blockchain technologies also promises to revolutionize the methods used to ensure the security of transportation systems. This approach can provide undeniable transparency in the supply and logistics processes, allowing you to track every stage of cargo

movement and increasing the level of security against counterfeiting and abuse.

It is important to note that ensuring safety in transport should not be limited only to high technologies, but also requires an integrated approach, including employee training, compliance with requirements and standards, as well as constant updating of security protocols. Regular training programs and emergency simulations will help prepare both employees and passengers for possible threats, which in turn will create a safer environment.

Cooperation between international bodies such as the United Nations and the World Trade Organization can contribute to the development of unified safety standards, which will make international transportation safer and more reliable. The creation of a global database on incidents and responses to them will allow countries to share experiences and prevent the recurrence of mistakes.

Solving the problems of transport security requires an integrated approach, including both technical and organizational measures, as well as working with the human factor and raising awareness among citizens. This will create a safer transport environment, protecting both passengers and cargo transportation from various threats.

V. CONCLUSION

Thus, the study provided an overview of the information technologies used in the transport industry by type of transport. Shortcomings in the adoption of current IT solutions were identified and sources of threats to transport security were established. This made it possible to justify the need to implement an automated information system (AIS) project in order to improve risk management processes.

The main feature of the AIS is the transformation of primary operational information into effective information. It maximally facilitates decision-making to eliminate sources of threats and ensure transport security. Significant attention in the work of the AIS is paid to the formalization of the processing of current information. The use of digital technologies is aimed at analyzing huge amounts of data in real time and predicting possible incidents with a preliminary response to them. Specially trained personnel monitor the processing and use of effective information.

To achieve a high level of security in transport, a comprehensive and integrated strategy is needed that covers technological, social and economic aspects. This requires close cooperation from all participants, the development of innovative solutions and readiness for emerging challenges.

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Wireless Integration of Fiber Optic Vibration Sensor

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Abstract—The article discusses approaches to integrating Internet of Things (IoT) technologies into a fiber-optic vibration sensor (FOVS). The paper examines modern technologies for wireless data transmission that allow expanding the possibilities of using such a sensor. The benefits of wireless connectivity are analyzed, including efficient, flexible and scalable monitoring, which improves production processes and increases the reliability of equipment operation. The paper discusses the connection scheme, the algorithm for processing the information received from the sensor, as well as the protocols for transmitting and processing data.

Keywords—sensor, IoT, vibration, fiber, optic

I. INTRODUCTION

This Disturbances in the operation of industrial equipment can be caused by an increased level of additional vibrations of these devices. The increase in the amplitude and frequency of these oscillations increasingly shortens the service life of the equipment [1]. In order to determine the exact cause of vibrations and take the necessary measures to eliminate them, it is recommended to inspect the equipment using special devices. There are many solutions for vibration diagnostics, among which non-contact ones are the most promising, since this measurement method does not distort the measured vibration and is not affected by electromagnetic interference [2,3]. This makes it ideal for detecting unwanted equipment vibrations.

Fiber-optic vibration sensor (FOVS) [4] is connected to a personal computer (PC) via a serial port, which entails a number of restrictions in terms of the dissemination of measured information.

First of all, the range of use of the sensor is limited by the length of the wire. For production, this means that a large number of cables must be laid. Moreover, the possible number of connected FOVS does not exceed the number of USB interfaces of a particular PC. When connecting new sensors, additional cables are required, which can be difficult in limited space or in existing infrastructures.

In addition, the information received from vibration sensors can be needed by several services at the same time, each of which uses this data to solve its own problems. Given that the number of sensors working simultaneously in production and the number of services to which information needs to be provided can be large, the existing solution needs to be improved.

The use of Internet of Things (IoT) technologies for this purpose makes it possible to solve all the problems described. The use of wireless communication will ensure the collection of data from a large number of geographically dispersed sensors. If necessary, they can be installed in places where it is difficult for a person to diagnose and establish a wired connection. The wireless connection makes it easy to expand the sensor network, as it is limited only by the communication range. Data from the server can be received by all interested services, at any distance from the network.

Thus, FOVS wireless connection is an urgent task aimed at improving the efficiency of monitoring systems, which is especially important in the context of increasing requirements for the safety and reliability of industrial facilities and infrastructures.

In this work, an attempt is made to develop a reliable device for measuring the vibration characteristics of equipment with the ability to interact with IoT technologies. The paper discusses a connection scheme that allows you to obtain the most convenient and functional design of the sensor at the lowest cost. The algorithm for processing information from the sensor and the protocols for transmitting and processing data are considered.

II. PRINCIPLE OF OPERATION AND STRUCTURE OF A FIBER-OPTIC VIBRATION SENSOR

An externally modulated fiber optic vibration sensor is a sophisticated device designed to measure the vibration characteristics of various objects [5]. Such a sensor is widely used in environments where high measurement accuracy is important, as well as insensitivity to electromagnetic and radiation interference, which makes it ideal for use in industrial facilities [6-8].

The FOVS in question allows you to detect vibration at frequencies from 10 to 1000 Hz. The range of measured amplitudes of vibration displacement is 0.1 ... 2 mm. The limits of the permissible basic relative error of vibration displacement measurements in the range of operating amplitudes and frequencies is no more than 5%.

FOVS uses the OTDR principle of obtaining measurement information. The vibration of the object causes a change in the intensity of the light flux that hits the photosensitive element. These changes are recorded and converted into an electrical signal, the magnitude of which is proportional to the amplitude of vibrations.

Structurally, the sensor is made in the form of two modules: a measuring part and a computing unit [8]. FOVS includes two optical measurement channels. Based on the analysis of the data obtained by the measuring channels, vibration parameters are calculated. The IR LED, which has a narrow radiation pattern, is used as a radiation source in the conductive channel of the transducer. The FOVS measurement channel consists of a light propagation path (optical fibers), photodetectors, a filter to eliminate the influence of non-informative factors, a signal amplifier and an analog-to-digital converter (ADC).

The second part of FOVS is the compute unit. The task of the computing unit is to calculate the vibration parameters of the measured object of analog voltage entering the input of the computing unit, as well as to compensate for the influence of external non-informative factors (for example, the reflectivity of the measured object) on the measurement results. At present, the basis of the computing unit is the K1986BE92QI microcontroller. It contains two 12-bit ADCs, can run at up to 80 MHz, has 128 kilobytes of Flash memory and 32 kB of RAM, which is enough to perform the task of measuring vibration. Calibration of the sensor and transfer of measurement information to a PC is carried out via UART.

For measurements, information about the sensor's working area is stored in the controller's memory, which can be configured earlier in the sensor calibration process. The principle of operation of FOVS is as follows: when the sensor element is located at a distance of the working area from the object of measurement, the calculation of vibration parameters begins. In measurement mode, the input data is also the ADC reading taken from the connected measuring part. The output data is the data on the read signal, as well as program statuses, special codes or measurement results transmitted via the UART protocol to the PC.

For correct operation, it is necessary to calibrate the sensor during the initial configuration of the sensor or change the operating conditions of the device. The algorithm of the meter is presented in Fig. 1.

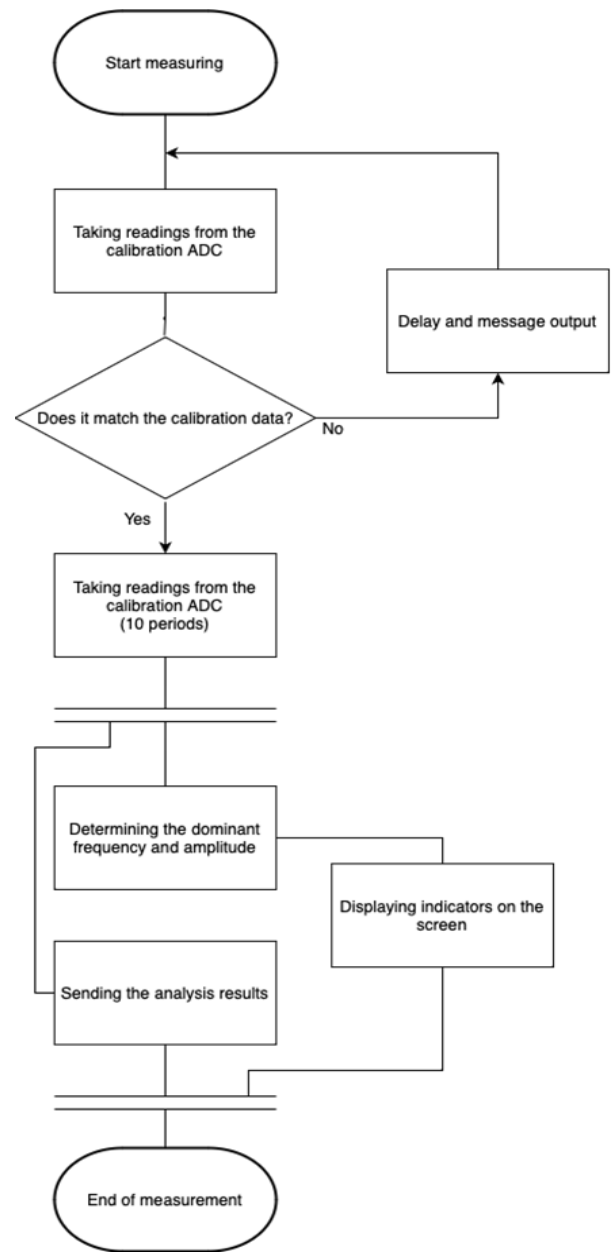


Fig. 1. Measurement algorithm

III. COMMUNICATION TECHNOLOGY AND MESSAGING PROTOCOL

The compute unit does not have built-in wireless communication modules, but it does have UART, SPI, and I2C interface controllers, which will allow you to connect almost any wireless communication module.

To work in shop floor conditions, the selected communication technology must provide a sufficient range of several tens of meters. When the sensor is powered from a battery, for correct long-term operation, it is necessary to use equipment with minimal energy consumption. In addition, it is necessary that the network deployed using this standard is reliable and easily scalable, and also requires a minimum amount of additional equipment. The preferred option is to use a mesh topology in which the end devices themselves can relay signals from other end devices, if necessary. Modern mesh protocols have built-in mechanisms that ensure the reliability and scalability of the network. For example, when existing nodes fail or new ones are added, the network recalculates the routes for data transmission. Currently, communication technologies with different data ranges are used to connect sensors to the IoT: from tens of centimeters

to several kilometers. NFC [9] has insufficient range for use in industrial premises, while NB-IoT, LTE-M [10], EC-GSM-IoT, SigFox [11] and LoRa [12] have an excessively long transmission range communications, or require the purchase of relatively expensive equipment, which is often impractical.

One of the most popular communication technologies used to build IoT networks is Wi-Fi [13]. It has a high data transfer rate, but is relatively energy-consuming, which prevents its use in autonomous sensors.

The release of a device using Z-Wave [14] technology to the market is complicated by the presence of different operating frequencies in different territories, as well as the need to be certified by one of the certification offices subordinate to the creator of the protocol, which complicates the development of devices.

Zigbee [13], Thread [15], and Bluetooth Low Energy (BLE) provide ample range. Zigbee and Thread support the default mesh topology, BLE requires additional services and libraries. Thread is a relatively young technology, but already has excellent support thanks to the open-source OpenThread implementation released by Google and maintained by many large companies. In addition, according to the results of benchmarking from SiliconLabs [16], the connection range of Thread is shorter than that of BLE mesh, but longer than that of Zigbee. Of these three technologies, Thread provides the highest throughput and lowest latency. Based on the above advantages, Thread communication technology was chosen.

The messaging protocol will be the Constrained Application Protocol (CoAP) [17]. It's based on a RESTful architecture, compatible with the IPv6 and UDP that Thread is built on, and designed to minimize data overhead.

IV. SOLUTION STRUCTURE DIAGRAM

As previously described, FOVS includes two optical measurement channels and a computing unit. To implement Thread wireless communication as part of a compute unit, you need a transceiver that supports IEEE 802.15.4 [18]. Border Router is also required to deploy the network and enable communication with external devices. The solution scheme is presented in general form in Fig. 2.

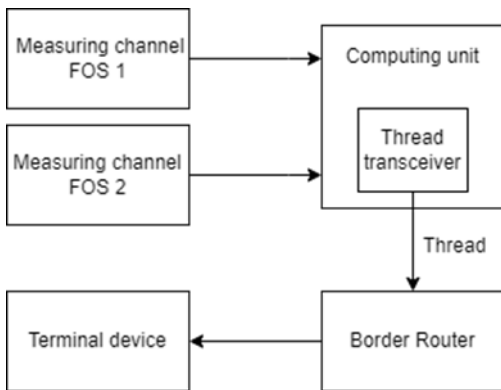


Fig. 2. Solution diagram

V. CONNECTION DIAGRAM

The K1986BE92QI microcontroller used in the FOVS control unit does not have a built-in Thread transceiver, so for a successful connection to the IoT network, it is necessary to modify the scheme of the computing unit. Since connecting an additional hardware module will increase the final size of the board, as well as the complexity and cost of

its production, the best option is to find an alternative to the microcontroller. The model used should support Thread data transfer, as well as a multi-channel high-bit ADC for processing signals from FOVS measurement channels, a digital-to-analog converter (DAC) for controlling the brightness of the IR LED, and a high clock speed for correct processing of the high-frequency signal.

The microcontroller does CC2652R74T0RGZR [19] meet the above requirements. It contains an eight-channel 12-bit ADC, an 8-bit DAC, can run at up to 48 MHz, has 704 kBytes of Flash memory and 256 kBytes of RAM, and supports the Thread wireless communication protocol, which will allow you to perform vibration measurement and messaging tasks.

To use it as a computing unit, it is necessary to connect the IR LED power circuit (DAC_OUT) to the DAC, and the measurement channel circuits (OUT_channel_1 and OUT_channel_2) to the ADC. The connection diagram is shown in Fig. 3.

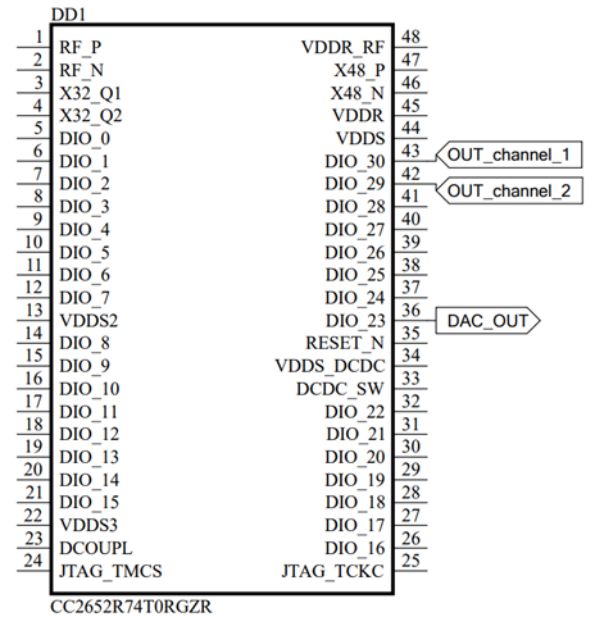


Fig. 3. Connection diagram

The Taking into account the features of the new computing unit, it is necessary to change the existing algorithm for collecting, processing and sending data from measuring channels. Develop software based on it using OpenThread's implementation for CC2652 microcontrollers and download it to the device.

On the receiving end, you need to use the Border Router to organize the network. This device should be able to install Linux or FreeRTOS to download the necessary software. In addition, there is an Ethernet or Wi-Fi interface for connecting to an external network, as well as a module for connecting to the Thread network.

A standard option is to use single board computers with a Linux operating system installed, such as BeagleBone Black, RaspberryPi 3 model B or later with a Thread-enabled microcontroller connected as a Radio Co-Processor (RCP).

Another option for creating a Border Router is to use two interconnected systems on a chip (SoC) [20] to communicate with multiple networks at the same time. For example, ESP32, ESP32-S, ESP32-C, etc. for Wi-Fi communication, connected to ESP32-H2 that supports IEEE 802.15.4 to communicate with the Thread network. A successful

implementation of this approach is the ESP Thread BorderRouter/ZigbeeGateway hardware module based on ESP32-H2-MINI-1 and ESP32-S3-WROOM-1 from Espressif.

This device supports Thread by default, while single-board computers require additional modules to be connected. In addition, the performance of single-board computers for use as a Border Router can be considered excessive, while the solution from Espressif has less power, less demanding components and, as a result, lower cost.

To implement a Border Router based on ESP Thread BorderRouter/ZigbeeGateway, OpenThread Border Router software must be installed. To do this, clone the repository from GitHub, build it, and configure it according to the documentation. Wi-Fi or Ethernet interfaces can be used to connect to external devices.

VI. CONCLUSIONS

As a result of the work done, a way to improve the existing FOVS using wireless technologies of the IoT was proposed. The main limitations of the traditional system, such as limited range and lack of scalability, were solved by integrating Thread technology using the CoAP protocol to enable wireless data transmission.

With this technology, it is possible to create a reliable, energy-efficient and easily scalable sensor network that can be implemented in harsh production environments. For the FOVS wireless connection, it was decided to replace the K1986BE92QI microcontroller with a CC2652R74T0RGZR in the control unit circuit for sending data via Thread, as well as to use ESP Thread BorderRouter/ZigbeeGateway as a Border Router.

In the future, it is planned to develop a circuit diagram of the control unit, as well as the program code of the SoC CC2652R74T0RGZR for the implementation of the device. For successful commercial use, it is proposed to create a data processing algorithm that simplifies the identification of the malfunction that caused vibration. In the future, FOVS with wireless communication over Thread is planned to be used to organize a network of sensors that allow you to effectively monitor the state of equipment in production.

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Improving Hardware and Software Systems for Monitoring Geomechanical Characteristics of Rocks in Boulder-Sand-Gravel Quarries

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Abstract— The paper presents a solution on improving hardware and software systems for monitoring the geomechanical characteristics of rocks in boulder-sand-gravel quarries.

Keywords— *boulder-sand-gravel quarries, intelligent systems, geomechanical monitoring, excavation monitoring*

I. INTRODUCTION

The rapidly developing construction industry demands an uninterrupted supply of high-quality non-metallic products. The construction of road bridges, as well as the reconstruction of ports, airports, and other industrial and civil facilities, are the primary consumers of high-quality crushed stone. Crushed stone constitutes the main product derived from non-metallic mineral raw materials, accounting for 85-95% by volume, along with crushed sand and gravel. As a crucial filler in concrete for the construction of critical infrastructure, it is essential that crushed stone ensures the reliability of these structures under extreme conditions. The quality of these products is regulated by GOST 8267-93 "Crushed Stone and Gravel from Dense Rocks for Construction Works." According to existing standards, crushed stone with a strength classification ranging from M1000 to M1400 must contain no more than 5% weak rock grains relative to the total mass. For crushed stone with strength classifications from M400 to M800, the allowable content of weak rock grains is limited to 10%. Crushed stone with a crushability grade lower than M400 is generally not utilized in road construction and repair.

The boulder component of the mineral raw materials (fraction greater than 70 mm) has a yield of 20.4%, with eruptive and metamorphic rocks constituting 81% of this component, highlighting its high value. Sedimentary rocks, which negatively impact the quality of the boulder component, account for only 19%. The gravel component comprises fractions ranging from 20 to 70 mm, with 66% composed of eruptive and metamorphic rocks and 34% made up of sedimentary rocks. However, the unpredictable variability of mineral raw materials—where the content of boulder and gravel material fluctuates between 20% and 70-

85%—poses challenges in maintaining product quality and ensuring a rational product nomenclature. In particular, deviations in quality can lead to significant losses; exceeding the threshold of more than 5% weak rock grains in crushed stone classified from M1000 to M1400 can result in an underestimation of both the grade and value of the product. This situation necessitates additional production capacities for mining, processing, and storing unclaimed finished products. Therefore, innovative approaches are required to uncover additional reserves. The objective of this project is to promote hardware and software systems for monitoring the geomechanical characteristics of rocks in boulder-sand-gravel quarries for effective product quality management. The most valuable portion of useful mineral raw materials consists of boulder-sand-gravel mixtures derived from eruptive rocks, such as granites and diorites, which are characterized by high bulk density and strong structural properties. The localization of mineral raw materials can be achieved through geomechanical zoning of boulder-sand-gravel quarries based on monitoring the excavation process. This geomechanical zoning will provide additional reserves, thereby enhancing the efficiency, product quality, and environmental safety of geotechnical operations. It will also increase the reliability of planning and improve the effectiveness of current management practices in mining operations and the processing of mineral raw materials.

The unpredictable variability of rocks leads to irregular operation of quarry equipment and an irrational structure of the output range and quality of products, which increases the ecological load on the environment and the costs associated with the storage of unused products and waste. It is possible to allocate tasks for the geomechanical zoning of boulder-sand-gravel quarries in relation to current management and future planning. These tasks are interconnected. The variability of boulder-sand-gravel deposits complicates effective forecasting of technological indicators and management due to insufficient information, even within the explored contours of the deposit.

II. METHODS

The most readily available indicator characterizing the content of the most valuable gravel-boulder component in the rock mass is the volumetric weight. The volumetric weight of the rock mass can vary widely (1.4-2.6 t/m³). Operational determination of the volumetric weight of rocks with satisfactory accuracy will help solve management problems in addition to zoning. When planning and designing mining operations, the value of the volumetric weight of the excavated rock mass is crucial. It is not by chance that established methods suggest calculating parameters and design indicators for overburden mining works exclusively in cubic meters (m³). In mining practice, there are many examples where rocks with differing volumetric weights are extracted from the same deposit. If these rocks are geometrized in the design, then their extraction requires the selection of different equipment corresponding to the characteristics of the rocks. Particularly in coal deposits, overburden rocks and mined coal, which differ in volumetric weight, are geometrized in space.

When the content of gravel-boulder material changes from 10% to 85%, the weight of rock in the bucket of a 4.6 cubic meter excavator varies from 6.0 tons to 10.0 tons, which adversely affects the final technical and economic indicators of the company. The lack of operational means to monitor the variability of the volumetric weight of excavated rocks prevents the regulation of dump truck loading in the flow of rock mass. Even theoretical calculations indicate that at the minimum content of boulders and gravel, there is an underload of 20%, while at the maximum content, there is an overload of 21%.

Thus, the main problems associated with the current management of boulder-sand-gravel quarries—specifically, improving the quality of the flow for processing and increasing the efficiency of loading dump trucks—can be addressed through geomechanical monitoring. To tackle the issue of geomechanical zoning of rocks, a complex criterion for dividing the rock mass into streams based on quality is proposed. This criterion includes the limiting value of the volumetric weight of the excavated rock mass and the limiting value of scooping duration. The logic for

implementing the tasks of geomechanical zoning in boulder-sand-gravel quarries is presented in the block diagram in Fig.1. The detailed operation of blocks [9, 11, 12, 13, 14] related to current control is realized through the algorithm shown in Fig.2. In this algorithm, which addresses current control tasks, emphasis is placed on the practical components of monitoring and controlling changes in the volumetric weight of the rock mass during excavation. This involves determining and maintaining the specified levels of volumetric weight and mass of the rock mass in the body of the dump truck.

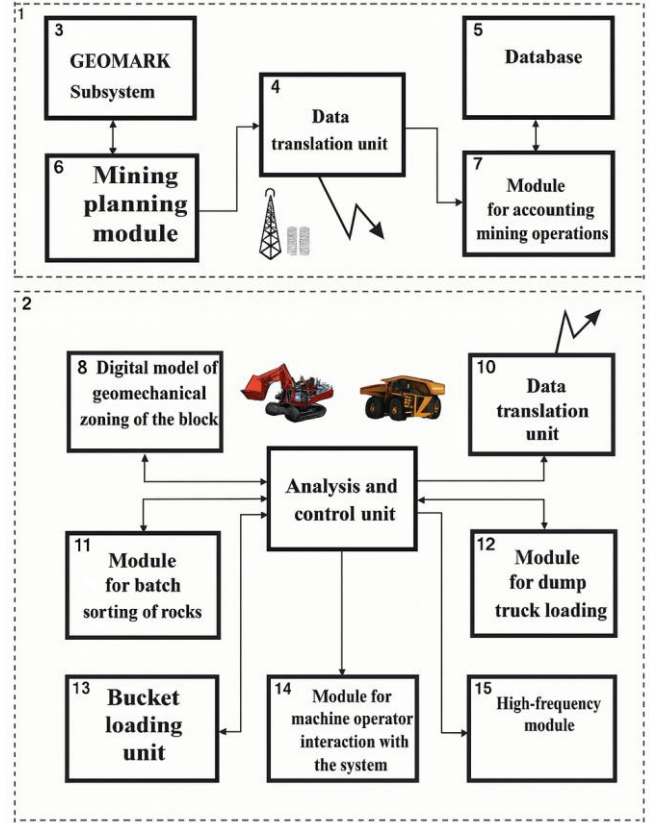


Fig. 1. Block diagram of logic for implementing geomechanical zoning in boulder-sand-gravel quarries

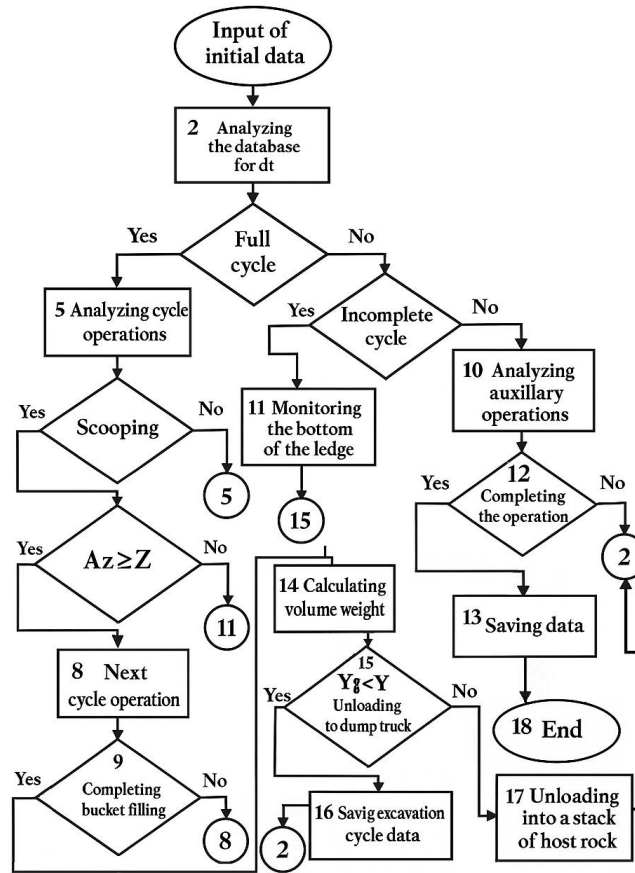


Fig. 2. Algorithm for geomechanical monitoring and batch sorting of rock mass

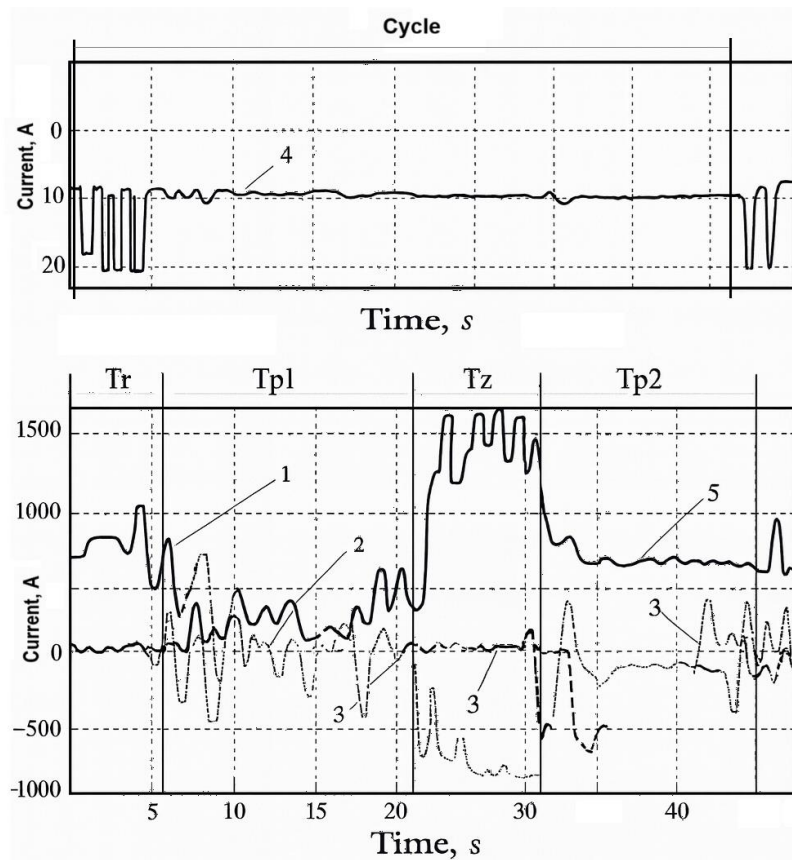


Fig. 3. Diagram of motor currents for head, lifting, turning and bottom opening. 1,2,3,4 - diagrams of currents of motors of lifting, head, turning and bottom opening, 5 - interval of the diagram relating to the operation of bucket unloading.

rock mass in the dump truck body is maintained. Specifically, if the rock mass in the excavator bucket meets the criteria set in step 15, the bucket is unloaded into the dump truck body. If it does not meet these criteria, the contents of the excavator bucket are unloaded into a temporary rock stack, from which the rock mass is subsequently directed either to the dump or to a temporary rock sorting stockpile.

Industrial experiments were conducted at the Malkinsky quarry in the Stavropol Territory to assess the effectiveness of linking the energy performance of the head, lift, and slewing motors to the operations of the excavation cycle over time. The design of the hardware-software complex in the

cabin of the EKG-4.6 excavator included a personal computer connected to galvanically isolated analog-to-digital converters (ADCs) from four modules of the MCX52-x.x series, which were used to measure motor currents (head, lift, slewing, and bottom opening).

To link the motor currents of the head, lifting, turning, and bottom opening to the operations of the excavation cycle, a subsystem based on MEMS technologies was utilized. This subsystem consists of two parts: a bucket position registration unit, which is fixed with magnets at the end of the excavator bucket handle, and a control module located in the excavator cabin. The joint operation of these units for monitoring the excavation process is facilitated by Wi-Fi.

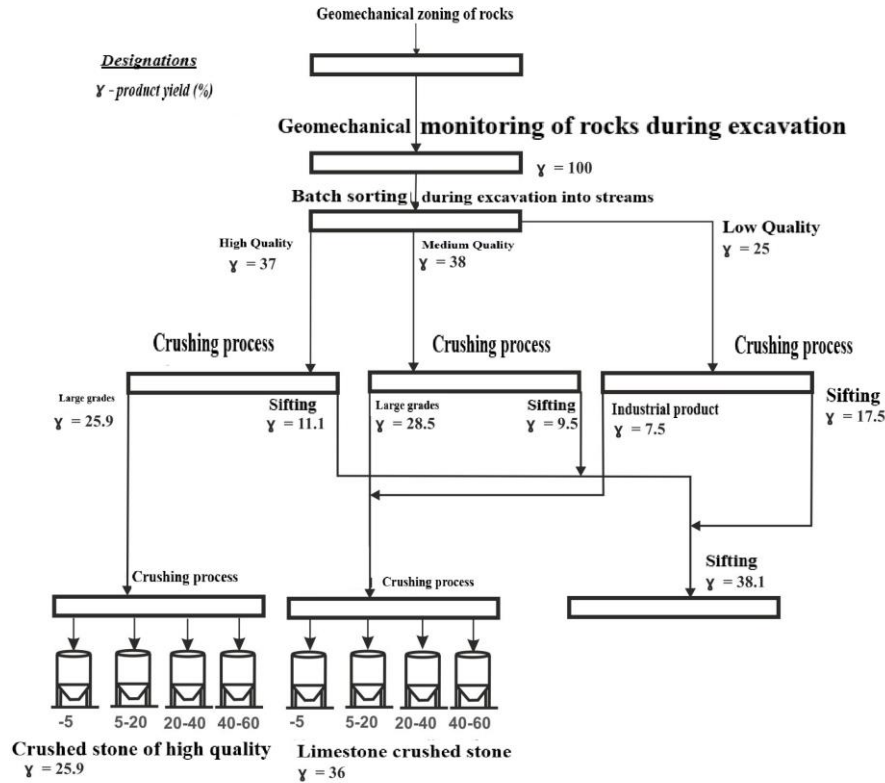


Fig. 5. Technological framework for monitoring of geomechanical characteristics of rocks of boulder-sand-gravel quarries and product quality management. Y - product yield.

III. RESULTS AND DISCUSSION

As can be seen from the block diagram and algorithm, the use of AIC allows for solving the problems of geomechanical zoning of rocks in real time through monitoring changes in rock characteristics. It enables portion monitoring of rock mass during the loading process. Since the costs of granite and limestone crushed stone differ significantly, this portion sorting is designed to greatly enhance the efficiency and profitability of production by separating valuable boulder-sand-gravel mineral raw materials from sedimentary rocks in a distinct process flow. This solution will ensure compliance with quality standards, as the most valuable crushed stone with strength from M1000 to M1400 should contain no more than 5% of weak rock grains relative to the total mass.

Figure 5 presents the technological framework for monitoring geomechanical characteristics of rocks in boulder-sand-gravel quarries and product quality management. The principle of constructing this technological scheme takes into account the general patterns of distribution

of weak sedimentary rocks. When the boulder component contains up to 19% sedimentary rocks, the gravel component with fractions sized 20-70 mm has an increased content of sedimentary rocks, reaching up to 34%. The fine fractions smaller than 20 mm consist of 65-70% sedimentary rocks. Thus, geomechanical zoning of rocks, particularly real-time monitoring of changes in rock characteristics, significantly expands the possibilities for current management of mining operations aimed at improving profitability and environmental safety in mining production.

IV. CONCLUSION

This methodology entails assessing the optimization efficiency of mining and processing parameters. Within this framework, the economic implications of contemporary technological and operational adjustments may be observed both in the short term (quantifiable by the conclusion of a month, quarter, or year) and over extended horizons. Furthermore, geomechanical zoning technology—which integrates differentiated reliability assessments into long-

term strategic planning—has the potential to reduce mining production costs by 18–20%. Given the proportionate impact of mining operations within the cost structure, this approach is projected to yield an aggregate reduction in production expenditures of approximately 16%.

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Development of the Lane Change System Based on Reinforcement Learning Paradigm Considering Different Types Drivers' Behavior

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Abstract—The problem of lane change is one of the key tasks in the field of vehicle control. In order to improve safety, comfort, and reduce travel time, vehicle manufacturers develop advanced driver assistance systems (ADAS), and the lane change system is included in this group of systems. Lane changes occur in a dynamically changing environment. The behavior of other traffic participants may differ in their driving style, which in turn affects their decisions when driving. This paper will present the development of a lane change system based on reinforcement learning (RL) using a model of the behavior of other traffic participants, taking into account different driving styles. The Deep Deterministic Gradients Policy (DDPG) algorithm will be considered as a base RL algorithm for generating of control signals. A multi-lane motorway with a lane merging zone is used as a road model. The average speed of the car and the number of lane changes were used as metrics for evaluating the operation of the lane change system.

Keywords—lane change system, autonomous vehicle, reinforcement learning, MOBIL

I. INTRODUCTION

Improving the quality of movement on public roads is one of the most important tasks solved by car manufacturers, construction and maintenance of road employment companies. Advanced driver-assistance systems (ADAS) development is the key trend of the automotive industry. Thus there are opportunities for the development and implementation of complex information high-load systems based on artificial intelligence methods to improve the safety of vehicle movement. The lane change problem is one of the key problems in the process of movement in the flow, and errors in the decision-making process about the maneuver lead to a decrease in the safety of movement and the mean velocity of the controlled vehicle. Developments in the field of maneuvering process management provide an opportunity to increase the safety and the efficiency of movement.

Lane change system consists of two main parts:

- 1) Decision-making system,
- 2) Planning system.

Decision-making system receives the information about other traffic participants' coordinates and speed values from the perception system and gives guidance to the Planning system. Particularly, the Decision-making system sends necessary coordinates, velocity and other constraints which are based on other traffic participants' behavior and this information is used by the Planning system to produce the

desirable acceleration and steering angle values. Finally, the control system generates control signals [1].

For creation of this lane-changing model data-driven method can be used [2]. One of the way is use of the Reinforcement learning paradigm [3], which allows to form the self-adapted and non-trivial policy. One of the best suitable RL method is DDPG [4].

Generally, for simulation of lane-changing behavior of other traffic participants the minimizing overall braking induced by lane change model (MOBIL) can be used [5]. But in case of non-trivial and non-standard road condition it takes more information for the lane-changing model for creation of more adapted policy of movement.

In this article we consider several problems:

1) Observing of other traffic participants driving behaviour model, which is based on cluster analysis of real section of the road [6].

2) Developing of pipelines based on DDPG with LSTM block for other traffic participants movement prediction which are trained with use of three scenarios: other traffic participants lane change behaviour based on MOBIL with politness variable equals 0 and 1 respectively for each scenarios and scenario and when traffic participants lane-changing behaviour based on cluster analysis of real road. The validation of three models will be provided in simulation when traffic participants have lane-changing behaviour based on cluster analysis of real road.

In section Traffic participants trajectories prediction the LSTM based method is observed. In section Lane-Changing System model DDPG based model is observed and the reward function is created. In section Other participants driving behavior the method based on cluster analysis is observed. In section MOBIL the MOBIL model of the lane-changing behavior is observed. In the Section Experiments the experiments will be described.

II. TRAFFIC PARTICIPANTS' TRAJECTORIES PREDICTION

Long short-term memory (LSTM) [7] is the key method for object moving prediction. It uses information about the sequence data about objects to build a learning model. This is possible thanks to a special memory function, which is the core part of LSTM.

The key part of the traffic participants' trajectories prediction block is LSTM decoder. The decoder structure is used for prediction of the obstacle traffic participants' trajectories with setting connection between the anterior and

posterior trajectory coordinates of the car. LSTM prediction model is pretrained and has accuracy 0.82. Movement forecasting horizon is 3 seconds.

III. LANE-CHANGING SYSTEM MODEL

DDPG is an algorithm that combines ideas from two fields: DPG (Deterministic Policy Gradients) and DQN (Deep Q-Network). DDPG is suitable for tasks with continuous action, and it has become the basis for, for example, vehicle driving, specifically, vehicle acceleration and steering wheel angles, are continuous actions.

The goal of DDPG is to maximize the expected sum of rewards (called cumulative reward) by optimizing the parameters of the actor and critic. This is done using an objective function called the "Actor-Critic Loss" [8].

The structure of the DDPG algorithm consists of 4 networks. Two target networks: the target policy network and the target Q-network, and two online networks: the online policy network which is called Actor Network and the online Q-network which is called Critic Network.

Critic Network receives an action μ from Actor Network and generates the action a respectively to the state s_t . Loss function for L which is used for increasing the action value, can be expressed as:

$$L = \frac{1}{n} \sum_i^n (Q(s_i, a_i | \theta^Q) - y_i)^2, \quad (1)$$

$$y_i = R_i + \lambda Q^-(s'_i, \mu^-(s'_i | \theta^{\mu^-}) | \theta^{Q^-}) \quad (2)$$

where n is the sample number, R_i is the reward function value of sample i ; λ is the discount factor, θ^Q denotes the parameter of the online Q-network, θ^{Q^-} is the parameter of the target Q-network, $Q(s_i, a_i | \theta^Q)$ is the action value which is got after evaluation with use of the online critic network, and $Q^-(s'_i, \mu^-(s'_i | \theta^{\mu^-}) | \theta^{Q^-})$ is the future action value which is got after evaluation with use of the target actor and target critic networks.

State information for RL model is introduced with two types of information:

- 1) Drived vehicle's position and speed;
- 2) Traffic participants' position on lane, velocity and predicted trajectories.

Action space of Lane-changing model includes the wheel angel value and acceleration value. Actions are got from actor network: $A[t]: \{a[t], \delta[t]\}$, where a is an accuracy value and δ is a wheel angel value.

Reward function consists of three parts: safe reward, efficiency for traffic reward and comfort reward. We can define several equations:

$$D_{safe} = vt + D_{-default}, \quad (3)$$

where $D_{-default}$ is the safe distance, t is the special coefficient, v is the car velocity, and D_{safe} is the distance which is safe for the car at a given velocity.

$$r_1 = \begin{cases} -k_c, & \text{if } d < L_{vehicle} \\ -k_{sd}, & \text{if } d < D_{safe} \\ -k_{wt}, & \text{if } y > L_{lane}, \delta \geq 0, \\ -k_{wt}, & \text{if } y < L_{lane}, \delta \leq 0, \end{cases} \quad (4)$$

where $L_{vehicle}$ is the length of the car, k_{wt} expresses the penalty for an incorrect turn, k_{sd} expresses the penalty for non-compliance with the distance, k_c expresses the penalty

for collision, L_{lane} is the length of the ego car, d expresses the distance between the ego and preceding cars and y expresses the lateral coordinate of the ego car.

Efficient driving means not speeding or changing lanes without reason:

$$r_2 = -d_t, \quad (5)$$

where d_t is the simulation step size.

The last part of the reward function is comfort. The key idea is that the comfort part can be determined using the following equation:

$$r_3 = \frac{1}{1 + |a| + |\Delta a|}, \quad (6)$$

where a expresses the acceleration of the car, and Δa expresses its jerk.

Finally, the total reward can be determined using the following equation:

$$R = \omega_1 r_1 + \omega_2 r_2 + \omega_3 r_3, \quad (7)$$

where ω_1 , ω_2 and ω_3 are the respective weight of the reward function involved in safety, lane-changing efficiency, and comfort. The safety weight is related to traffic rules and decision making regarding traffic conditions. The lane change weight value is related to the decision making process related to acceleration and deceleration during driving. The comfort weight is related to the acceleration and jerk of the car.

IV. OTHER PARTICIPANTS' DRIVING BEHAVIOR

Car-following model is introduced with the Intelligent Driver Model (IDM) [9] and can be expressed as:

$$a_n(t) = \frac{dv_n(t)}{dt} = a_0 \left(1 - \left(\frac{v_n(t)}{v_0} \right)^4 - \left(\frac{s_n^*(t)}{s_n(t)} \right)^2 \right) \quad (8)$$

Where $a_n(t)$, $v_n(t)$ and $s_n(t)$ are the acceleration of car n , velocity of car n and actual distance between neighbor cars at time t respectively, $s_n^*(t)$ denotes the desired distance between neighbor cars, a_0 and v_0 denote the peak acceleration and desired velocity of car n in flow without obstacle. $s_n^*(t)$ can be expressed as:

$$s_n^*(t) = s_0 + T v_n(t) + \frac{v_n(t) \Delta v(t)}{\sqrt{2 a_0 b}} \quad (9)$$

Where T denotes safe headway, $\Delta v(t)$ is speed difference between neighbor cars. b expresses the desired deceleration.

TABLE I. CAR-FOLLOWING PARAMETERS

Categories of driving	Maximum acceleration a_0 (m/s ²)	Desired vehicle v_0 (m/s)	The minimum gap s_0 (m)	Safe headway T (s)	Comfortable deceleration b (m/s ²)
Aggressive	2.5	19.10	1.5	1.5	4
Normal	2.0	16.93	2.0	1.5	3
Conservative	1.5	15.44	2.5	1.5	2

Lane-changing model includes three parts: lane-change intention generation which is connected with lane-change motivation function, conditions judgment which is connected with maneuver safety estimation and lane-change execution which is connected with desired speed achieving.

Lane-changing intention generation step includes creation of motivation of function for lane change maneuver. Several

factors such as safety, velocity and comfort are key parts of multi-objective optimization model which is expressed in Formula 10:

$$F(x) = \omega_1 f_1(x) + \omega_2 f_2(x) + \omega_3 f_3(x) \quad (10)$$

where $f_1(x)$, $f_2(x)$, $f_3(x)$ represent velocity function, comfort function and safety function, respectively. ω_1 , ω_2 and ω_3 are the weights for these functions.

$$\begin{cases} f_1(x) = -(v_d - v_c) \\ f_2(x) = -\sum_{t=0}^{T_{ic}} |a_{lat}(t) + a_{lon}(t)| \\ f_3(x) = d_s - (y_{new} - y_{behind}) \end{cases} \quad (11)$$

where v_d is the desired car velocity, v_c is the current car velocity, a_{lat} denotes the lateral acceleration, a_{lon} denotes the longitude acceleration, d_s denotes the safety gap, y_{new} expresses the position after lane change, y_{behind} expresses the position of the following car on the target lane.

Safety distance d_s is crucial factor of safe lane changing. In this article it can be determined based on the Gipps model [10] and can be expressed as:

$$d_s = \max \left(0, v_b \cdot t + \frac{v_b^2 - v_f^2}{2a_{max}} \right) \quad (12)$$

where v_b and v_f denote the speed of the following and leading cars in target lane, respectively. t is the reaction time from 1 to 2 second, a_{max} denotes the following car maximum deceleration.

When there is opportunity to change lane in both left and right direction it is necessary to calculate d_s for both lanes:

$$d_s = \max \begin{bmatrix} \max \left(0, v_{b,r} \cdot t + \frac{v_{b,r}^2 - v_{f,r}^2}{2a_{max}} \right) \\ \max \left(0, v_{b,l} \cdot t + \frac{v_{b,l}^2 - v_{f,l}^2}{2a_{max}} \right) \end{bmatrix} \quad (13)$$

where $v_{b,r}$ and $v_{f,r}$ denote the speed of the following and leading cars in the right target lane, respectively, $v_{b,l}$ and $v_{f,l}$ denote the speed of the following and leading cars in the left target lane, respectively.

Also, for expression of drivers' desire to reduce travel time, driving smoothness and congestion avoidance. Thus, revenue function C , that is included in final motivation function, can be expressed as:

$$C = \gamma_1(T_c - T_{new}) + \gamma_2(C_c - C_{new}) \gamma_3(D_c - D_{new}) \quad (14)$$



Fig. 1. Road scheme

“Selfish” traffic participants politeness p_0 equals 0 and “altruistic” traffic participants politeness p_1 equals 1.

For third scenario aggressive drivers is 18% of traffic participants, normal drivers is 63% of traffic participants, conservative drivers is 19% of traffic participants. Traffic density is 15 vehicles per km per lane. In Table III driving behavior speed parameters of different driving behavior and in Table IV driving behavior parameters.

where $\tilde{a}_n$ denotes new acceleration of new follower car after possible maneuver of ego-vehicle. b_{safe} is safe deceleration.

The motivation criterion for lane changing, when neighbor traffic participants included in decision-making process, can be expressed as:

$$\tilde{a}_c - a_c + p(\tilde{a}_n - a_n + \tilde{a}_o - a_o) > \Delta a_{th} \quad (21)$$

where $\tilde{a}_c$ denotes new acceleration of ego-vehicle c after possible maneuver. a_c is the acceleration before ego-vehicle c maneuver. Lane changing can be executed if a moving in new lane will be faster. a_n is the acceleration before maneuver of ego-vehicle c . $\tilde{a}_o$ denotes new acceleration of new follower car after possible maneuver of ego-vehicle c , a_o is the acceleration before maneuver of ego-vehicle c . The politeness factor p is special weight which expresses the degree of ego-vehicle altruism. The value of p is in range of $[0,1]$. If p equals 0, it means, that ego-vehicle c has selfish behavior and doesn't take in to account the dynamics of other traffic participants. On the contrary, if p equals 1, it means that for ego-vehicle c own acceleration changing is the same importance as accelerations changing of involved cars. Finally, Δa_{th} denotes the special switching threshold and allows to prevent the ego-vehicle from lane-changing maneuver if it will not be profitable compared with keeping lane.

V. EXPERIMENTS

For training and validation of lane-change model the six-lane highway with merge area. During each iteration, the start and finish points are formed, taking into account the direction of movement on the road section on which these points are located. Route scenarios may include driving on a freeway, exiting, and entering a freeway. The algorithm of the lane change system is trained using three scenarios.

First scenario learning occurs when other traffic participants use the MOBIL model to make lane change decisions where politness factor p equals p_0 , which means that traffic participants are “selfish”.

Second scenario learning occurs when other traffic participants use the MOBIL model to make lane change decisions where politness factor p equals p_1 , which means that traffic participants are “altruistic”.

Third scenario learning occurs when other traffic participants have lane-changing behaviour based on cluster analysis of real road to make lane change decisions.

TABLE II. DRIVING BEHAVIOR SPEED PARAMETERS OF DIFFERENT DRIVING BEHAVIOR

Categories of driving	Maximum speed (m/s)	Average speed (m/s)	Standard deviation of speed (m/s)
Aggressive	19.10	17.12	1.38
Normal	16.93	14.64	1.15
Conservative	15.44	13.69	1.02

TABLE III. DRIVING BEHAVIOR PARAMETERS

Categories of driving	Acceleration (m/s ²)	Deceleration (m/s ²)	Lane changing duration (s)
Aggressive	0.18	0.16	2.74
Normal	0.13	0.15	3.32
Conservative	0.12	0.11	4.16

The training hyperparameters set consists of: max training period is 1024, sample size is 64, learning rate is 0.001, discount factor λ is 0.99.

The validation hyperparameters set consists of: max valid period is 1024, sample size is 64.

In this simulation for the DDPG algorithm the Critic network part consists of three fully connected layers with dimension 10x256, 256x256 and 256x1 respectively. The Actor network part consists of three fully connected layers with dimension 8x256, 256x256 and 256x2 respectively. Activation function after each layer is ReLU. For reward function penalty coefficient k_{wt} is 5, k_{sd} is 5, k_c is 10. ω_1 is 5.0, ω_2 is 2.0 and ω_3 is 1.0.

Value of acceleration can be equal from -5 to 5. Wheel angle can be equal from -15° to 15°.

For analysis and comparison, we consider two metrics: average speed and number of lane change of ego-vehicle.

TABLE IV. COMPARISON OF RESULTS

	Average Velocity (m/s)	Average lane change number
First scenario	22.3	13
Second scenario	18.8	5
Third scenario	25.6	6

VI. DISCUSSION

After conducting a series of experiments, several conclusions can be made.

The model trained with a politeness coefficient of $p = 1$ (the second scenario) showed the lowest results for average speed and the number of lane changes during the validation process. This is due to the fact that in driving conditions where other traffic participants do not make sharp and sudden maneuvers, the model forms a policy in which there is less adaptation to an aggressive environment and there is no need to adapt to a sharply changing road situation and make additional maneuvers, such as evasive maneuvers.

The model trained on the first scenario, where the politeness coefficient $p = 0$, achieved improvements in average speed compared to the second scenario. But the number of lane changes is the highest, indicating the formation of a movement policy adapted to an aggressive and rapidly changing environment, but at the same time the emergence of a tendency to search for and explore new movement options.

The model trained according to the third scenario showed a significantly better result in terms of average speed and an intermediate result in terms of the number of lane changes, but the number of lane changes is not significantly greater than that of the model trained according to the second scenario. Thus, the third training scenario achieved optimal results for the efficiency and safety of movement. But it is worth noting that the creation of a model of the behavior of other road users in the third scenario requires more time and resources. This can only be justified in the case of a non-trivial traffic situation, when it is necessary to give the model the opportunity to form a policy more adapted to the given area.

VII. CONCLUSION

In this work two lane-changing behaviour models were observed: MOBIL and the behaviour model based on cluster analysis of real road to make lane change decisions. Three training pipelines which use three different training scenarios were developed. The differences were in lane-changing behavior of other traffic participants. Under different condition lane-changing system of the vehicle could form different policies. The model trained on third scenario achieve best results, but it takes more time and calculation resources for analysis of a road area. It makes sense in case of non-trivial and non standard road conditions.

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Comparative Analysis of Bibliometric Platforms for Meta-Analysis of Scientific Publications: A Case Study on the Economic Behavior of the Indigenous Peoples of the North

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Abstract— This article presents a comparative analysis of the functional capabilities of bibliometric platforms (Dimensions, Lens.org, OpenAlex, and PubMed) in conducting a meta-analysis of scientific publications addressing the economic behavior of Indigenous peoples of the North. The research methodology employs a reproducible search experiment with standardized query parameters, complemented by expert validation of the relevance of the retrieved results. The study reveals that none of the platforms provides comprehensive coverage or sufficient accuracy when working with thematically and linguistically specific publications. This finding underscores the need for developing specialized tools to analyze scholarly content in humanities and interdisciplinary research domains.

Keywords—comparative meta-analysis, digital research ecosystems, AI-driven research infrastructure, metadata extraction, multilingual indexing, cultural knowledge systems

I. INTRODUCTION

In recent years, the demand for systematizing and analyzing scientific data concerning the Indigenous Peoples of the North has intensified, reflecting the priorities set by national and international strategies focused on preserving cultural heritage, protecting the rights of Indigenous communities, and promoting the sustainable development of traditional ways of life. Contemporary challenges, including the need for comprehensive studies of the economic behavior, social practices, and demographic trends of these communities, require the application of digital tools capable of processing heterogeneous and multilingual datasets.

In 2024–2025, Russia adopted and updated key strategic documents shaping the trajectory of scientific and digital technology development. The National Strategy for Artificial Intelligence Development until 2030 (2024) and the federal project Artificial Intelligence (2024–2030) explicitly provide for the advancement of AI methods for big data analysis in social and ethnographic research, as well as funding for the development of neural network tools designed for traditional ethnic communities, including the Indigenous Peoples of the Russian North. Strategic direction in the field of digital

transformation of science and higher education, approved by the Government of the Russian Federation in 2021, emphasizes the integration of artificial intelligence and neural network methods to systematize scientific data, including in interdisciplinary research in ethnology and sociology.

At the international level, both the UN Declaration on the Rights of Indigenous Peoples and ILO Convention No. 169 emphasize the imperative of ensuring the accurate and comprehensive representation of the culture, history, and socio-economic conditions of the Indigenous Peoples of the North. Achieving this objective is unattainable without the use of advanced tools for the analysis and meta-analysis of scientific publications. The Introduction of the Code of Ethics in the field of AI demands transparency and accountability in data processing, making the comparison and selection of optimal neural network models not only a scientific, but also a socially significant task.

Thus, the relevance of this article lies in its alignment with state priorities in digitalizing science, advancing artificial intelligence, and protecting the rights of the Indigenous Peoples of the

North to preserve and develop their traditional way of life. In the current context, only the integration of neural network methods into publication meta-analysis workflows can ensure the completeness, accuracy, and representativeness of scientific data necessary for informed decision-making in ethnocultural policy, sustainable development, and the preservation of Russia's Indigenous cultural heritage.

II. METHODOLOGICAL BASIS OF COMPARATIVE ANALYSIS OF BIBLIOMETRIC PLATFORMS

This study aims to conduct a reproducible (i.e., replicable when applying identical search parameters) comparative analysis of the functional characteristics of bibliometric platforms used for thematic meta-analysis and bibliometric assessment of scientific content [1].

The study examines leading bibliometric platforms, including Dimensions, Lens.org, OpenAlex, and PubMed, widely applied in scientific research as key instruments for sourcing bibliographic data and supporting meta-analyses across multiple disciplines [1, 2, 3, 4]. These platforms were selected based on the following criteria: open or partially open access, widespread adoption in academic practice, availability of filtering and data export mechanisms, and technical compatibility with visualization tools.

In this research, these platforms served as data sources for the meta-analysis of scientific content. For the visualization and analysis of bibliometric networks, the specialized tool VOSviewer was used, which enables constructing maps based on co-authorship, co-citation, term co-occurrence, and network analysis. The effectiveness and widespread use of VOSviewer in scientific research are supported by multiple publications [5, 6].

The empirical part of the study examines publications addressing the economic behavior of the Indigenous Peoples of the North, representing a research area characterized by pronounced contextual and linguistic specificity [7, 8, 9]. The findings can also be extrapolated to other subject areas characterized by heightened terminological and linguistic sensitivity.

The choice of this research focus reflects the need to assess the applicability of bibliometric platforms to analyzing publications marked by high terminological complexity, limited representation in digital databases, and the use of multiple languages within a single corpus. Similar limitations are encountered when working with publications on ethnolinguistic groups, regional anthropology, folklore studies, language diversity, and localized forms of traditional knowledge — topics often insufficiently covered by existing meta-analysis tools due to language-specific content, source localization, and irregular indexing.

The methodological objective of this study is to assess the suitability of existing bibliometric platforms for processing scientific content with pronounced thematic and linguistic specificity, using publications on the economic behavior of the Indigenous Peoples of the Russian North.

To evaluate the suitability of the examined platforms for processing publications with thematic and linguistic specificity, we established the following assessment criteria:

- typological positioning – determining whether the platform functions primarily as a scientific data aggregator, search engine, or visualization tool;
- data openness and accessibility – examining availability of free access, API support, and options for machine-readable data export;
- multilingual support capabilities – assessing the platform's ability to process Russian-language queries while accounting for terminological variations and synonyms;
- available filtering parameters – analyzing tools for refining search results by publication type, date, and source;
- compatibility with visualization systems – evaluating export functionality for metadata formats supported by VOSviewer and similar analytical tools;
- semantic search and AI features – examining the depth of natural language processing, thematic

clustering capabilities, and conceptual relationship mapping.

The evaluation of each platform's relevance, accuracy, and result completeness will involve a controlled search experiment using standardized keywords and constraints. These findings will be additionally verified through expert evaluation by researchers specializing in the economic behavior and social practices of the Indigenous Peoples of the Russian North.

The search experiment followed a standardized procedure for extracting bibliographic data from four platforms: Dimensions, Lens.org, OpenAlex, and PubMed. This phase aimed to assess each system's ability to generate relevant samples of scientific publications on the economic behavior of the Indigenous Peoples of the North under standardized search parameters.

Our platform assessment revealed that Lens.org, OpenAlex, and PubMed provide unrestricted access to core functionalities without requiring user registration. In contrast, Dimensions necessitates registration to access advanced features, including detailed metadata and refined filtering options. All platforms offer interfaces exclusively in English. However, our testing confirmed that automated translation via Google Chrome and Yandex Browser ensured accurate navigation and content comprehension without structural distortions.

The study implemented the following standardized search queries (adapted to each platform's syntax): (economic behavior) OR (economic mind) AND (indigenous) AND (peoples) AND (north). Uniform filters were applied across all searches:

- Document type: journal article,
- Publication language: English,
- Publication period: from 2000 onward.

Where available, advanced settings incorporated additional filters by subject area, publication source, and indexing status. Results were quantified by publication count and qualitatively assessed through title relevance, keyword presence, and thematic alignment.

Search queries were manually adapted to account for the syntactic requirements of each platform, including the use of Boolean operators, wildcards, truncation symbols, and field-specific search constraints. Where advanced settings were available, additional filters were applied based on subject area, publication source, and indexing status. Search results were recorded both quantitatively (by the number of retrieved publications) and qualitatively — assessing the proportion of relevant titles, the presence of keywords in texts, and the degree of thematic alignment.

The presented methodology for comparative analysis and search experimentation is reproducible, provided there is open access to the platforms used, adherence to the specified query parameters, and identical filter settings. However, potential limitations of the study must be considered, including the dynamic nature of database updates, variations in search and indexing algorithms, and the lack of full multilingual query support across platforms.

Additionally, certain platforms impose restrictions on automated data extraction and processing. For instance, services such as ResearchGate and Google Scholar do not support automated retrieval and export of publication

datasets in machine-readable formats suitable for subsequent analysis and visualization.

This study highlights the distinction between web scraping and parsing, each serving different purposes and presenting unique methodological considerations. Web scraping refers to the automated extraction of data from web pages using specialized tools, enabling the retrieval of information from HTML code when official data export mechanisms are unavailable. However, this approach entails legal and ethical constraints and requires careful attention to source usage policies [10, 11, 12].

Parsing, in contrast, involves syntactic analysis and structuring of data obtained either through officially supported export formats (e.g., CSV, JSON, RIS, BibTeX) or other representations. In bibliometric and scientometric research, parsing is a crucial step in data preparation for analysis and visualization, ensuring standardization into compatible formats [13].

These approaches are particularly relevant in studies analyzing publication trends and thematic mapping of scholarly content. Their selection and application depend on both the technical capabilities of the platforms and the ethical, legal, and research-specific requirements. In this study, only officially supported data export and processing methods were employed [14], strictly adhering to the terms of use of the respective platforms.

III. RESULTS

The platforms were comparatively analyzed using functional and technical parameters relevant to bibliometric analysis of thematically and linguistically specific publications. The table below summarizes the results of interaction with four platforms included in the search experiment.

The results presented in the table demonstrate that none of the platforms offers comprehensive functionality required for analyzing publications with high terminological variability and cross-linguistic structure.

TABLE I. COMPARATIVE ANALYSIS OF FUNCTIONAL CHARACTERISTICS OF BIBLIOMETRIC PLATFORMS: A CASE STUDY ON THE ECONOMIC BEHAVIOR OF INDIGENOUS PEOPLES OF THE NORTHABLE TYPE STYLES

Platform	Access without registration	Interface language	Compatible with VOSViewer	Filter support	Multilingual search	Exporting Data export	Relevance comment
Dimensions	No partially	English	Yes (CSV)	Yes	No	Yes	Limited number of results, but thematically closer to the query
Lens.org	Yes	English	Partly	Yes	No	Partly	Broad coverage, but a significant amount of irrelevant content
OpenAlex	Yes	English	Yes (JSON → CSV)	Partially restricted	No	Yes	High completeness, but the output includes a lot of noise publications
PubMed	Yes	English	Yes (via RIS/BibTeX)	Yes	Partially MeSH-terms, Eng.	Yes	The scope is limited, but the accuracy is high within the limits of biomedicine

The platforms Lens.org, OpenAlex, and PubMed provide free access to basic features, while Dimensions requires registration for advanced functionality. OpenAlex and Dimensions show the best compatibility with visualization tools, particularly VOSviewer, whereas PubMed requires intermediate processing of exported data, and Lens.org has limitations in export formats.

The most significant differences were observed in semantic search and filtering capabilities, where Dimensions and PubMed demonstrate comparative advantages. However,

the absence of multilingual search across all platforms remains a key limitation, especially when working with publications related to Indigenous peoples of the North.

To gain a deeper understanding of the limitations and potential of bibliometric platforms, we conducted an expert survey (N = 12) involving structured interviews with researchers specializing in the economic behavior and social practices of the Indigenous Peoples of the Russian North. The main findings of the expert survey are presented in Table 2.

TABLE II. SUMMARY OF EXPERT RESPONSES TO STRUCTURED INTERVIEW QUESTIONS

№	Criteria	Content
1	Specific parameters of the economic behavior of indigenous peoples that are not sufficiently represented in the platforms.	- Insufficient accounting of data on traditional farming (reindeer husbandry, fishing, hunting). - Lack of information on resource allocation mechanisms in communities. - Poor coverage of the impact of traditional institutions (for example, family relations) on the economy. - Insufficient representation of data on social capital and intangible cultural heritage (traditions, knowledge, skills) related to economic activity. - There is almost no data on the environmental knowledge of indigenous peoples that affects their economic strategy.
2	The impact of the lack of support for indigenous languages on the conduct of research.	- Restriction of access to important sources of information that are not available in English or Russian (community reports, conference proceedings, regional publications, folklore). - Difficulties with the search, translation and analysis of texts in the languages of Indigenous peoples. - Loss of nuances and context in translation, distortion of the meaning of traditional concepts and concepts. - The lack of tools for automatic processing and analysis of texts in indigenous languages makes it difficult to identify patterns and trends. - Existing platforms are mainly focused on English-language literature, which leads to a systematic bias in the sample and ignoring important research published in other languages.
3	Additional data sources required for analysis.	- Population census data containing information on employment, income, education, and other socio-economic characteristics of indigenous peoples. - Statistical data on the production of products of traditional types of management, the standard of living, social infrastructure. - Data from surveys conducted directly in the communities, allowing you to get first-hand information. - Environmental monitoring data describing the state of natural resources used by indigenous peoples. - Results of ethnographic research describing traditional practices, knowledge, and beliefs. - It is necessary to use geographic information systems (GIS) for visualization and analysis of spatial data.

№	Criteria	Content
4	Important features missing from existing platforms.	- Tools for analyzing complex relationships between various factors (for example, climate impacts on reindeer husbandry and its economic consequences). - Tools for working with data on seasonal migration of the population associated with traditional types of management. - Ability to integrate heterogeneous data (texts, maps, photos, videos) into a single analytical environment. - Tools for automatic recognition and analysis of texts in indigenous languages. - The ability to model economic processes that take into account the specifics of traditional institutions and environmental factors.
5	Keywords, terms, and search strategies to improve search accuracy.	- Use of a wide range of keywords, including terms in the indigenous languages, synonyms and slang terms. - Expansion of the search by geographical regions, including the places of residence of indigenous peoples. - Use search operators (Boolean operators, proximity operators) to more accurately identify queries. - A combination of search queries filtered by subject area (for example, economics, sociology, anthropology, ethnography). - Use of thesauri containing terms related to the economy and culture of indigenous peoples.

The expert survey results corroborate the findings of the search experiment. On average, experts rated their satisfaction with current platforms at 60%, highlighting significant shortcomings and the need for specialized solutions. The most effective approach for further analysis was found to be a combined methodology using OpenAlex for comprehensive coverage and Dimensions for precise sample refinement and data export.

The search query “(economic behavior) OR (economic mind) AND (indigenous) AND (peoples) AND (north)” retrieved 220 research articles dated from 2000 onward on the Dimensions platform. However, article screening revealed that the majority of these publications were

irrelevant, as they contained no information about the Indigenous Peoples of the Russian North. Irrelevant articles covered topics such as biodiversity, climate change, racism, disability, substance abuse, religiosity, homelessness, pregnancy, gender discrimination, smuggling, and others. Only 51 out of 220 articles were judged relevant by experts.

Subsequently, we visualized the search results using VOSviewer software (version 1.6.18). The analysis aimed to detect co-occurrence term networks present in article titles and abstracts. For this analysis, the software was instructed to consider only terms appearing more than 10 times. The procedure yielded 6 relevant, interconnected terms (Figure 1).

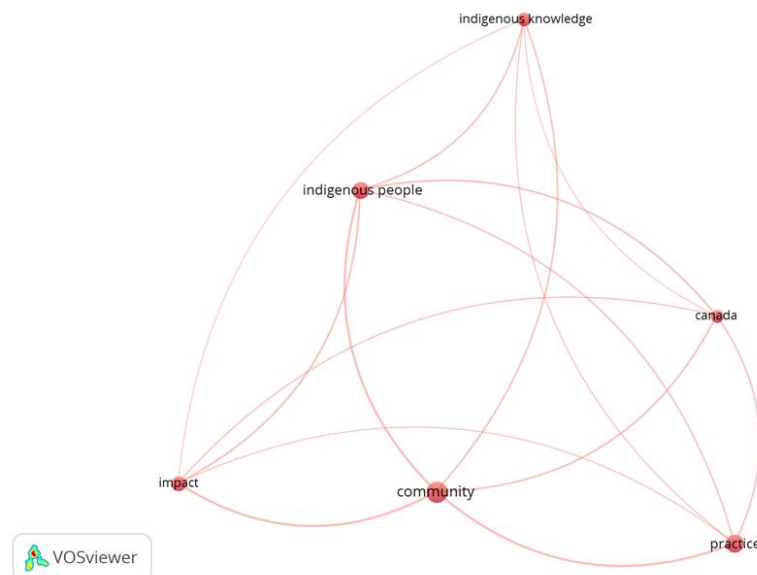


Fig. 1. Co-occurrence network of terms: Dimensions

As illustrated in Figure 1, the identified terms provide limited thematic depth, primarily indicating geographical context (Canada) and suggesting research focuses on societal impact, community values, indigenous knowledge systems, and traditional practices. These results highlight both the scarcity of specialized research on the studied topic within this dataset and the superficiality of the content analysis.

The same query was executed in the OpenAlex platform, yielding 156 articles, of which 139 were deemed relevant.

However, due to technical constraints preventing file modification within the program, all 156 articles were loaded into the visualization system.

Visualization of search results using VOSviewer software (version 1.6.18) with identical parameters revealed a more comprehensive set of terms, which the program organized into three distinct clusters (Figure 2).

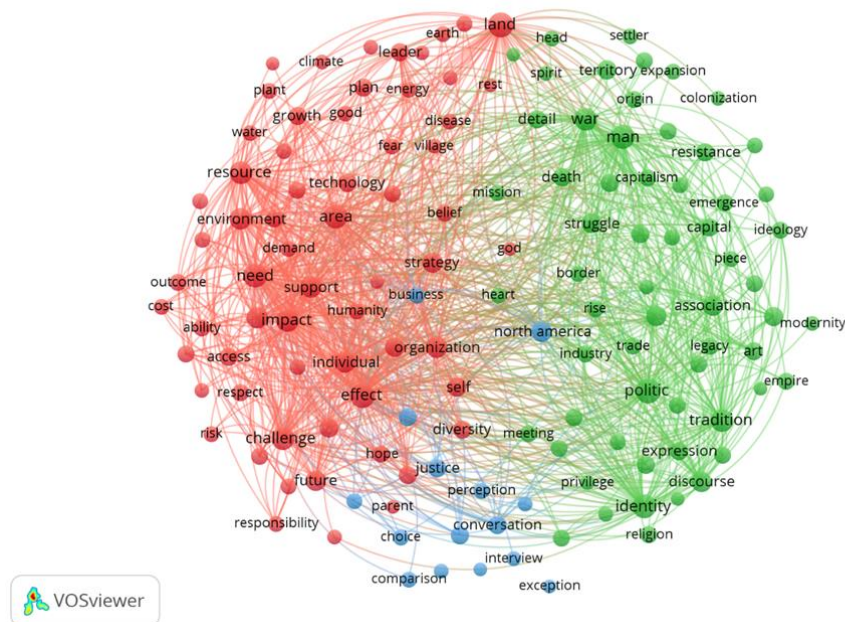


Fig. 2. Co-occurrence network of terms: OpenAlex

The first and most extensive cluster, marked in red, includes the following terms: access, need, agency, area, land, challenge, consumption, cost, money, crisis, effect, impact, environment, growth, resource, and others. This cluster appears to reflect a research focus on key economic challenges faced by the Indigenous Peoples of the North, including access to resources, climate change, land reduction, and related issues.

The second-largest cluster, highlighted in green, comprises terms such as american, association, border, colonialism, death, discourse, expansion, freedom, identity, Indigenous people, politic, resistance, struggle, war, and others. This cluster likely reflects a research direction centered on colonization and assimilation of Indigenous peoples (not limited to northern groups) as well as their political rights.

Finally, the third and smallest cluster (marked in blue) contains terms like business, canada, choice, conversation, expectation, insight, interaction, and others. This cluster appears to represent studies examining the integration of the economic behavior of the Indigenous Peoples of the North into the modern economy.

IV. DISCUSSION

The study results reveal both strengths and substantial limitations of contemporary bibliometric platforms for analyzing scientific publications on the economic behavior of Indigenous peoples of the North. The comparative analysis of Dimensions, Lens, OpenAlex, and PubMed indicates that none individually provides complete functionality for studying topics marked by high terminological variation, linguistic specificity, and contextual dependence. These findings align with conclusions from other researchers examining challenges in bibliometric analysis within specialized knowledge domains [1,15,16].

In the context of our study, it is important to note that Crossref, while not a platform for direct content search and analysis, played a key role in ensuring data connectivity. Thanks to the DOIs provided by Crossref, we were able to unambiguously identify and merge publications found across

different databases (Dimensions, Lens, OpenAlex, PubMed), avoiding duplication and creating a more comprehensive and structured sample.

Among the analyzed platforms, Dimensions presented the greatest challenges in ensuring the relevance of search results. Despite its advertised functional advantages in advanced filtering and semantic search mechanisms, this platform demonstrated the lowest precision in generating samples for highly specialized research topics. A distinctive characteristic of Dimensions' output was the substantial number of irrelevant publications whose content fell outside the study's subject area. Notably, the retrieved sample included works addressing such diverse topics as biodiversity, climate change, racism, disability, substance abuse, religious practices, social marginalization, pregnancy, gender discrimination, as well as criminal offenses and smuggling.

Unlike Dimensions, the Lens platform demonstrated high coverage completeness, retrieving the largest number of publications on the given topic. However, as with OpenAlex, this advantage was accompanied by low retrieval precision. Lens appears to index a broad range of sources, including not only academic journals but also preprints, conference materials, and other types of publications. This leads to a significant increase in "noise" and requires thorough manual filtering of search results.

OpenAlex occupied an intermediate position between Dimensions and Lens in terms of coverage and precision. It provided a reasonably broad scope of publications but fell short of Lens in this regard. At the same time, the relevance of OpenAlex's search results was somewhat higher than that of Lens but lower than PubMed's. This suggests that OpenAlex's algorithms are more sensitive to the thematic specifics of research on the Indigenous Peoples of the North than those of Lens, but less effective than PubMed.

PubMed, a platform specializing in biomedical research, showed the highest retrieval relevance among all the platforms examined. This is explained by PubMed's use of the controlled MeSH (Medical Subject Headings) vocabulary,

which allows for more precise identification of publication topics. However, PubMed's coverage remains limited, as its focus is predominantly on the medical and biological aspects of the lives of the Indigenous Peoples of the North, while studies addressing economic, social, and cultural issues are rarely included.

A significant limitation of all the analyzed platforms is the lack of multilingual support, as a substantial portion of research on the Indigenous Peoples of the North is published in Russian or Indigenous languages. This results in systematic sampling bias and the exclusion of important information sources from the analysis. Although platform interfaces can be translated using automated tools, this does not address the challenge of processing search queries and analyzing texts in different languages.

Given the identified strengths and weaknesses of each platform, the most effective approach is to combine PubMed for high-precision biomedical searches, OpenAlex and Lens for broader publication coverage, and Crossref for linking data from different sources and eliminating duplicates. Expert evaluation and manual filtering of search results remain necessary to ensure sample relevance.

These findings can also be extrapolated to other research areas characterized by high terminological and linguistic sensitivity, such as ethnolinguistics, regional anthropology, folkloristics, language diversity, and localized forms of traditional knowledge. These fields face similar challenges, including limited representation in digital databases, multilingual content, and high contextual dependency, necessitating the development of specialized tools and approaches for bibliometric analysis.

V. CONCLUSIONS

This study underscores the need to develop specialized solutions for bibliometric analysis of research topics characterized by high terminological and linguistic specificity. Such solutions should account for linguistic peculiarities, source localization, irregular indexing, data integration from diverse sources, and expert validation. Further research should focus on designing these solutions, incorporating expert recommendations, and evaluating their effectiveness across various subject areas.

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Operational Testing and Error Budget Management in the Architecture for Large Language Models Integrated Systems

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Abstract—The integration of large language models (LLMs) into information systems requires new architectural solutions to ensure security, reliability, and quality control. This paper analyzes vulnerabilities and testing challenges specific to LLM-integrated systems. We propose a new class of architecture tailored for LLM usage, based on a microservice paradigm with a centralized orchestrator. Special attention is given to operational testing as an architectural component for identifying defects in real-world environments, and to the use of fault budgets as a dynamic quality control mechanism. This approach enhances system adaptability and resilience under real-world usage and rapid AI evolution.

Keywords—*llm-integrated systems, operational testing, error budget, software architecture, microservices*

I. INTRODUCTION

The integration of Large Language Models (LLMs) into information systems (IS) significantly transforms approaches to automation, user interaction, and software development [1]. While LLMs demonstrate substantial potential in natural language understanding and generation tasks, their deployment in production environments introduces architectural risks associated with security, reliability, and quality management.

Modern LLM-integrated systems (LLMIS) often inherit design patterns from microservice architectures [2], but typically overlook the stochastic nature of LLMs [1], their sensitivity to prompt variations, and their vulnerability to adversarial inputs [3]. Particularly critical are threats such as environment variable leakage [4] and prompt injection attacks [5], which may lead to confidentiality breaches or unauthorized actions.

The lack of embedded operational testing mechanisms—intended to detect failures, assess vulnerabilities, and evaluate system quality in production settings [6]—combined with the absence of error budget management [7], impairs fault detection under real-world conditions and hinders objective reliability assessment.

This study proposes an architectural solution aimed at enhancing the level of security, reliability, and quality control in LLMIS operating under production conditions. The proposed design is based on a microservice paradigm and includes three key components:

- Operational testing mechanisms that enable real-time detection of failures and vulnerabilities when interacting with LLMs in production;

- An error budget management system that provides dynamic control over the acceptable level of deviations;
- A centralized orchestrator that analyzes metrics [8] and execution logs to coordinate the selection of LLM-based components and implement adaptive responses to detected instabilities.

Section II reviews related work on LLMIS security, quality assessment [8], and testing methodologies [6]. Section III outlines the proposed methodology, including the integration of operational testing and the extension of Kulikov’s testing classification [6] for LLMIS. Section IV presents architectural foundations and two reference architectures [1], [9]. Section V describes the proposed architecture and evaluation results. Section VI explores architectural evolution [10] and positions the proposed solution within this context. Section VII concludes the study and outlines directions for future research.

The primary contribution of this work is the development of an architectural model for LLMIS with integrated quality management mechanisms that account for the stochastic behavior of LLMs, thereby improving fault tolerance and adaptability in real-world deployment scenarios.

II. REVIEW OF RELATED PUBLICATIONS

A. Security of LLM-Integrated Systems

Systems built on LLMs pose distinct security challenges due to their sensitivity to input context, unpredictable behavior, and reliance on uncontrolled external data sources. Architectural principles such as Zero Trust [11] and Secure-by-Design [12] have become essential to ensuring security at the system design stage [13].

The OWASP Top 10 for LLM Applications (2025) [3] outlines the most critical threats for LLM-based applications, including prompt injection, environment variable leakage, model poisoning, and system prompt exposure. These vulnerabilities may be exploited both directly and indirectly, particularly in production environments where adversaries are capable of identifying system characteristics [14].

Prompt injection attacks are especially concerning due to their ease of execution and the current lack of robust mitigation mechanisms. Mudarova and Namiot [5] present machine-learning-based detection methods for identifying and blocking such attacks.

The Model Context Protocol (MCP) [15] further broadens the attack surface by allowing LLMs to invoke

external tools and perform remote operations. Recent studies have shown that misconfigured MCP settings may result in unauthorized command execution or leakage of credentials.

Some vulnerabilities in LLMIS are only observable in production environments, where data volume, model behavior, and infrastructure differ from those in test settings. Research shows [15], [16] that attackers may distinguish between test and production environments by analyzing indirect signals, such as domain names or response structure, and launch targeted attacks.

Environment variable leakage—often caused by weak runtime isolation—is a particularly dangerous threat [4]. LLM-based attacks may also use anti-analysis techniques to detect testing environments and suppress or adapt their behavior accordingly, executing malicious actions only in real-world operational conditions [4], [17].

These observations highlight the critical need for operational testing and error budget management, which are discussed in subsequent sections. Early detection of faults and vulnerabilities during the system lifecycle enables substantial reductions in recovery costs and significantly improves the reliability of production systems.

B. System Quality Assessment

To formalize quality management in LLMIS, it is appropriate to adopt concepts such as the Service Level Agreement (SLA), Service Level Objective (SLO), and Service Level Indicator (SLI) [8]. These metrics allow for a structured approach to evaluating the expected performance and reliability of system components in production environments.

The concept of an error budget [7] defines the acceptable margin of deviation from the SLO that the system can tolerate without breaching the SLA. It is mathematically defined as the difference between the ideal service level (100%) and the target SLO. This margin serves as a decision-making tool for balancing between system stability and the deployment of new features.

In the context of LLMIS, the error budget can be used dynamically—e.g., to select or reject a specific Artificial Intelligence (AI) agent based on its recent performance, or to trigger fallback strategies if the threshold of allowable errors is exceeded. This approach enables more adaptive, data-driven orchestration of probabilistic components within the architecture.

Furthermore, we propose an extension of this concept by applying the error budget as a mechanism to limit the number of attempts for executing resource-intensive, hard-to-reproduce, or unsolvable tasks using LLMs. This strategy is conceptually similar to the Rate Limiter design pattern found in microservice architectures [18], but it is adapted here to the specific interaction characteristics of LLMs.

Operational testing plays a critical role in this process by identifying vulnerabilities, failures, and behavioral anomalies that may only surface in real-world deployment scenarios. As discussed in subsequent sections, these real-time observations feed into the budget management system, enabling continuous quality control and increasing system robustness.

C. Testing of LLM-Integrated Systems

Traditional software testing principles, as defined in ISO/IEC/IEEE 29119-4 [19], in Kulikov’s classification [6], and in the book *Foundations of Software Testing: ISTQB*

Certification [20], remain applicable but require substantial adaptation when applied to LLMIS.

The paper by Jain and Wang [21] explores the unique challenges associated with testing software systems that incorporate LLMs and Multi-Agent LLM-based Systems (MALLM). These challenges reflect the inherent complexity and probabilistic behavior of such systems.

- Key characteristics of LLMIS testing include:
- Unpredictable and stochastic output behavior;
- Absence of deterministic test oracles capable of reliably verifying response correctness;
- The phenomenon of hallucinations, where outputs may be logically structured but factually incorrect;
- Application of metamorphic testing, where controlled input transformations are used to evaluate consistency in system behavior;
- Multi-turn dialogue structures that demand contextual memory and coherence;
- Ethical and legal constraints that must be observed to prevent generation of harmful, discriminatory, or non-compliant content.

III. METHODOLOGY

A. Operational Testing

Operational testing refers to the evaluation of system performance in a real-world production environment [6]. Related approaches, such as gamma testing and exploratory testing, are beyond the scope of this paper, but their relevance to LLMIS must be emphasized, as many vulnerabilities emerge only under actual operational conditions.

Key architectural elements that support quality assurance in LLMIS during production include:

- Microservice architecture, which ensures component isolation and flexible update cycles. The benefits of this approach for LLMIS are discussed in the following section.
- Canary release, a deployment technique in which a new software version is initially released to a limited group of users, enabling early detection of critical issues and rollback if needed [2]. This strategy is particularly suitable for updating language models, generation parameters, or AI agents.
- Circuit Breaker, a resilience pattern that prevents repeated requests to failing components. Modern implementations enhance this pattern using machine learning algorithms that dynamically adjust trip thresholds based on system state [22], often leveraging libraries such as Scikit-learn [23].

When combined with these architectural techniques, operational testing enables real-time fault detection and adaptive quality control for the system.

Error discovery methods in production environments for LLM-based systems are discussed in [21].

Mechanisms that contribute to improving LLMIS reliability during operation include:

- Dynamic reassessment of generation parameters (e.g., temperature, top-p);
- Limiting retry attempts based on the current error budget;
- Dynamic selection of AI agents from an approved list;
- Application of Zero Trust principles [11];
- Integration of self-diagnostic tools and mechanisms to flag potentially unreliable responses.
- Thus, operational testing is not only a validation mechanism under real-use conditions but also a key architectural element for enhancing the reliability, manageability, and security of LLMIS.

B. Augmenting Kulikov's Testing Classification with LLM-Integrated System Testing Methods

Given the specific characteristics of LLMIS and their limited representation in existing testing taxonomies, such as the classification proposed by Kulikov [6], it is appropriate to extend the testing framework with the following categories:

- *By component behavior model*: distinguishing between the testing of deterministic components and stochastic modules, such as LLMs;
- *By contextual sensitivity*: distinguishing between single-turn (context-independent) testing and multi-turn (context-dependent or dialog-based) testing;
- *By generation objective*: evaluating factual accuracy, logical coherence, stylistic conformity, and adherence to ethical standards.

This proposed extension highlights the need to revise current testing classifications to accommodate the evolving nature of LLM-based technologies. While not exhaustive, it sets a direction for future research aimed at formalizing testing practices for intelligent systems.

IV. ARCHITECTURES OF LLM-INTEGRATED SYSTEMS

A. Principles of Microservice Architecture Improving LLM-Integrated Architecture

The application of microservice architecture in LLMIS provides several advantages that are critical for the reliability and scalability of systems incorporating LLMs.

The key principles include [2]:

- *Independence from external services*: Decoupling the system from specific LLMs or AI agents allows switching to alternative components in the event of failure or provider changes;
- *Separation of responsibilities*: Components responsible for input processing, data access, and quality control are deployed as independent services, which reduces the risk of cascading failures;
- *Modularity*: Enables simplified deployment, deactivation, or substitution of system components without affecting the entire architecture;
- *Horizontal scalability*: Microservices that heavily utilize LLMs can be scaled independently, facilitating workload distribution and supporting multi-model environments;
- *Simplified release management*: Microservice principles allow incremental delivery of new features and reduce the complexity of system updates;
- *Support for Zero Trust and Secure-by-Design principles*: When working with local or cloud-based LLMs, it is critical to segment access to sensitive data and manage trust boundaries between services [11], [12].

These architectural principles enhance the adaptability, fault tolerance, and maintainability of LLMIS, particularly in continuously evolving and production-intensive environments. While other microservice principles exist, this section highlights those most relevant to the design of LLM-integrated systems.

B. Example 1. Generalized Architecture of an LLM-Integrated System

Figure 1 illustrates a commonly used architecture for LLMIS [1].

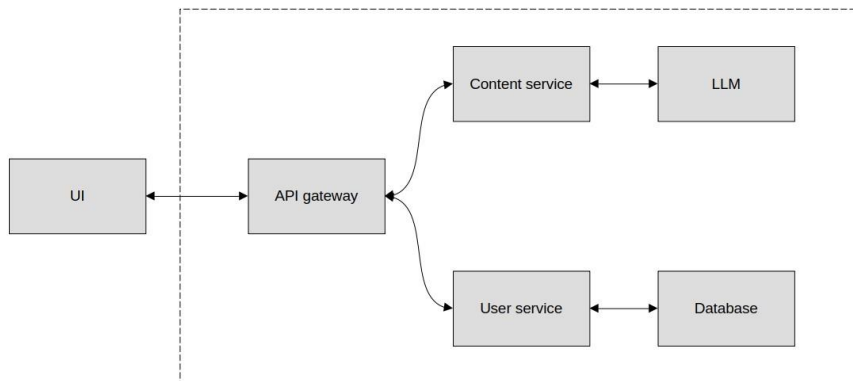


Fig. 1. Generalized Architectural Diagram of LLMIS

This architecture includes the following key components:

- *User Interface (UI)*: the primary layer for user interaction with the system;
- *Application Programming Interface (API) Gateway*: handles user requests and routes them to the

appropriate services. With additional configuration, it can also serve as an orchestrator;

- *User Service*: interacts with system infrastructure, such as the database;

- *Content Service*: responsible for generating and processing content, typically interacting with the LLM.

Depending on system requirements, additional components may be included. This architecture allows for the isolation of the LLM from the end user, introduces mechanisms for output control, and enables adaptive quality management via the API gateway.

C. Example 2. Reference Architecture for an LLM-Integrated System

Figure 2 presents a Reference Architecture (RA) for LLMS, organized into four layers: Presentation, Application

Logic, LLM Integration, and Data Management, each separated by dashed black lines. Every layer includes functional components (gray rectangles) and additional subcomponents (white rectangles) that illustrate example capabilities, with ellipses indicating potential extensibility. Two auxiliary components—Monitoring and Guardrail—span multiple layers. Connections between components are represented by directed arrows.

Following the microservice architecture paradigm, each component operates as an independent service, enabling modular updates and scalability of LLM-related functionality. A detailed description of the architecture and all services can be found in the original publication [9].

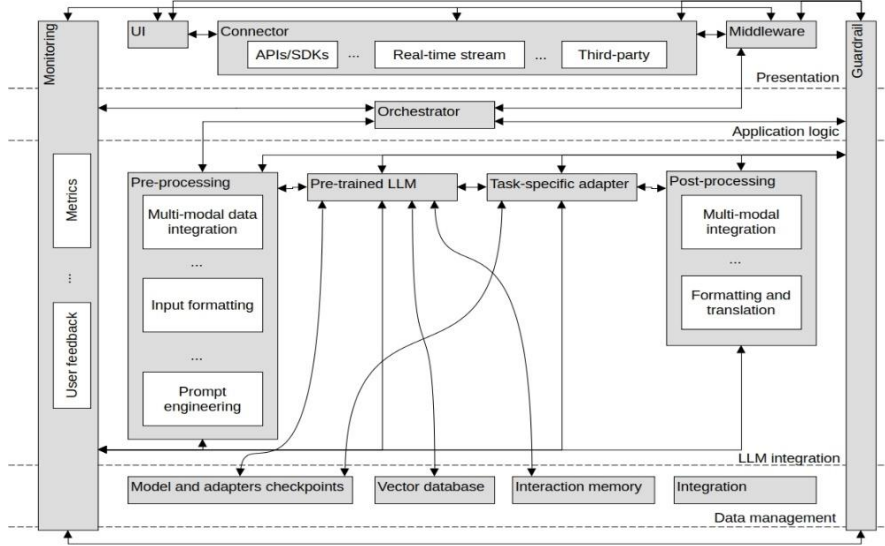


Fig. 2. Reference Architecture for LLMS

Building on the reviewed architectures and microservice design principles, the next section introduces our proposed improved architecture for LLMS.

V. PROPOSED ARCHITECTURE AND RESULTS

Figure 3 illustrates the enhanced architecture of LLMS,

developed based on the conceptual principles outlined in the previous section.

To visually highlight the differences from the reference architecture shown in Figure 2, all newly introduced or modified components are shaded in dark gray, while unchanged elements are preserved in their original form.

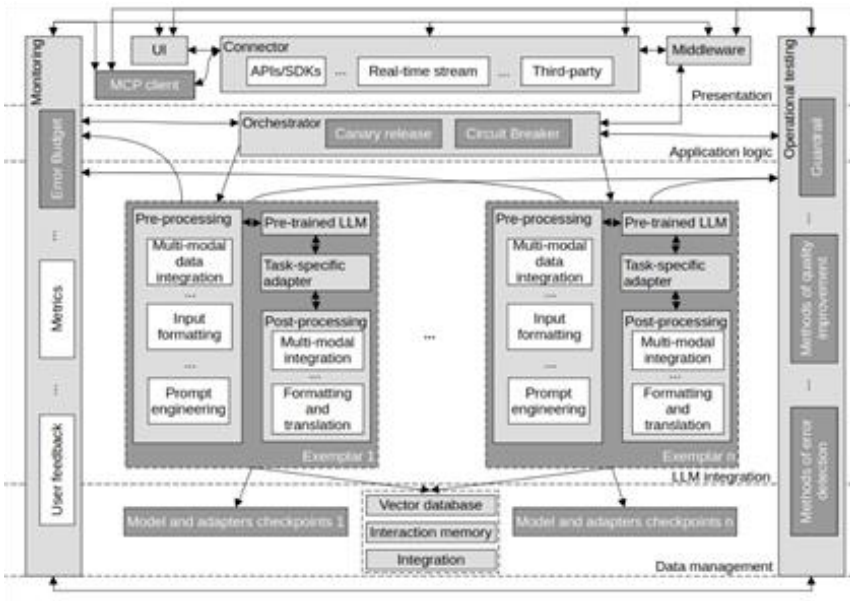


Fig. 3. Enhanced Architecture of LLMS

Key modifications include the following elements:

1) *Expanded interaction channels*: Support for access via an MCP client has been added, enabling unified interaction with LLMIS functionality through APIs, Software Development Kits (SDKs), and streaming interfaces, for both end users and third-party components.

2) *Integration of operational control mechanisms*:

- a) The monitoring layer now includes an error budget counter to assess the robustness of LLM outputs against predefined behavioral thresholds.
- b) The quality control component incorporates modules for error detection, generation quality improvement, and guardrails that restrict model output in accordance with security policies.

3) *Intelligent system behavior management*: Monitoring data and operational test results are forwarded to the central orchestrator, which manages releases using the canary release mechanism and ensures fault tolerance via the circuit breaker pattern, thereby mitigating the impact of failures and unpredictable component behavior.

4) *Scaling and diversification of LLM instances*: All core components associated with LLM invocation (preprocessing, model, adapters, postprocessing) are now deployed as multiple instances, allowing for:

- a) Distribution of incoming requests across different LLM configurations;
- b) Parallel operational testing;
- c) Deployment of multiple model versions or fine-tuned adaptations without disrupting the system's core functionality.

The proposed architecture aims to increase fault tolerance, behavioral predictability, and adaptability of LLMIS in response to the probabilistic nature of generative models and the evolving requirements of end users.

VI. DISCUSSION. ARCHITECTURAL EVOLUTION AND POSITIONING

This section presents the evolution of LLMIS and highlights the architectural abstraction level at which our proposed approach—based on operational testing and error budget management—is positioned.

Figure 4 depicts a typical architecture of an LLM-powered chatbot that performs the basic functions of an AI assistant—namely, interacting with users through natural language. Unlike AI agents, assistants do not exhibit autonomy and operate strictly within user-defined instructions.



Fig. 4. Chatbot

Figure 5 extends this model by integrating Retrieval-Augmented Generation (RAG) [1] through a toolchain, enhancing the assistant's ability to access and process contextual knowledge.

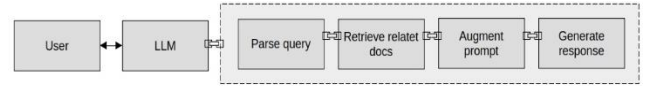


Fig. 5. AI assistant with a toolchain

The evolution of LLMIS has led to the emergence of autonomous AI agents capable of planning and invoking tools independently, as shown in Figure 6.

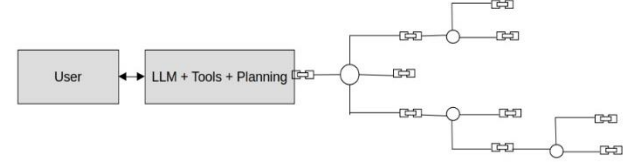


Fig. 6. FAI agent

Figure 7 introduces our enhanced LLMIS architecture. It includes a centralized orchestrator that selects system components—such as AI agents, LLM models, or external tools—based on real-time metrics collected through operational testing and monitored error budget thresholds. This diagram is a simplified representation of the architecture introduced earlier in Figure 3.

The approach is grounded in production-level testing aligned with SLO [8], including metrics from canary releases [2], load testing, and context-role alignment of active agents [1], [17]. These operational metrics form the basis for runtime decision-making, which we classify as operational testing [2]. Error budget management [7] is employed to tolerate a defined level of failure while improving the system's ability to achieve goals, analogous to Stochastic Gradient Descent (SGD) strategies [25], [26]. SGD is widely used in ML to find solutions in problems with unpredictable behavior [27].

This methodology equips the orchestrator with a formal mathematical framework and access to a broad spectrum of ML tools—including libraries such as Scikit-learn [24]—enabling adaptive selection of stochastic LLM-based architectural components, implementation of fault-tolerant patterns such as Circuit Breaker [23], and coordination within multi-agent environments [10].

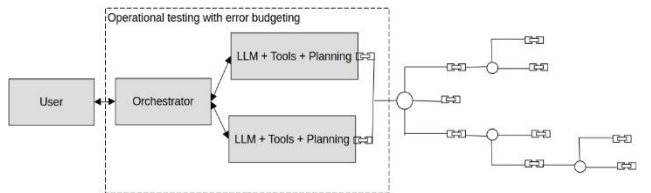


Fig. 7. AI agent with operational testing and error budget

Figure 8 provides examples of such multi-agent interactions. This concept forms the core scientific contribution of this work. The dotted rectangle in the diagram outlines the conceptual boundaries of the proposed approach, which is designed to remain separate from other system components.

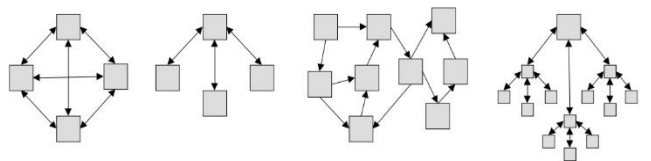


Fig. 8. Examples of multi-agent systems

The goal of this design is to enhance the overall reliability and quality of LLMIS under real-world operational conditions.

The presented improvement lays the groundwork for future multi-agent systems in which LLM-driven agents collaborate through the orchestrator, dynamically adapting to error rates and quality metrics.

The analysis conducted in this study supports the assertion that LLMIS architectures require robust frameworks and validated architectural solutions to ensure reliability, security, and adaptability in light of the stochastic nature of LLMs and the rapid pace of generative AI adoption in production information systems.

VII. CONCLUSIONS

This paper has examined architectural strategies for designing LLMIS, focusing on improving reliability and robustness under real-world operating conditions. Based on an analysis of current threats—such as prompt injection attacks and the leakage of sensitive information through prompt context and environment variables—it is evident that such systems require well-validated architectural solutions and frameworks. These must support enhanced quality, resilience to vulnerabilities, and adaptability to the unique characteristics of LLM integration.

To address these needs, we have proposed an enhanced architecture based on the microservice paradigm. It incorporates a centralized orchestrator, operational testing mechanisms, and error budget management components.

The proposed approach enables:

- Structuring LLMIS architectures to reflect the stochastic behavior of LLMs by embedding operational testing and error budget mechanisms as architectural elements;
- Identifying faults and vulnerabilities during real-world usage;
- Monitoring system quality based on production-level metrics;
- Reducing system coupling through service isolation;
- Increasing adaptability by delegating the selection of components and testing scenarios to a centralized orchestrator.

The primary limitation of the proposed architecture lies in the additional computational overhead introduced by operational testing in the production environment. Furthermore, system maintenance complexity may increase due to the higher number of infrastructure components.

Future work may include:

- Developing strategies for selecting agents and LLM components based on historical error data and real-time system status;
- Investigating architectural patterns tailored to multi-agent LLM-based systems;
- Analyzing the influence of error budget constraints on agent behavior and goal-oriented decision-making;
- Further formalizing LLMIS testing methodologies by combining traditional testing principles with LLM-specific practices.

This architecture represents a step toward establishing reliable design principles for LLMIS that are compatible with the demands of real-world operation and the evolving landscape of generative AI technologies.

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Machine Learning Approach for Monitoring the Condition of Forest Ecosystems

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Abstract— This paper presents a near-real-time forest monitoring system based on unmanned aerial vehicles (UAVs) and machine learning methods. The proposed approach addresses the limitations of traditional satellite systems by providing high-resolution images and environmental data processed during UAV landing using convolutional neural networks (CNN). The system enables accurate forest segmentation, species classification, and forest health assessment. Climatological indices such as vapor pressure deficit (VPD) and aridity index (AI) are used in the system to improve forest fire risk prediction. Computer simulation results demonstrate the effectiveness of the solution in identifying forest structure and fire hazard zones. An interactive map visualizes the analysis results to support decision making in forest management. The result of the work is a scalable and practical tool for environmental monitoring and early detection of forest degradation with potential applications in forest fire prevention and resource planning.

Keywords—*machine learning, remote sensing, cnn, environmental monitoring, decision support systems, image classification, climatological indices, geospatial analysis*

I. INTRODUCTION

The issue of environmental conditions and the protection of living nature remains relevant. With the development of industrial society, the number of production facilities and manufactories has multiplied, highlighting the problem of imbalance in the forest ecosystem due to pollution, mass deforestation, and forest fires. The forest is an invaluable asset and a strategically important resource that ensures the equilibrium of the entire biosphere, enhancing its integrity and supporting animal and plant life. This factor creates a need for effective and rapid solutions that allow for collecting up-to-date information on the state of forest areas in various zones. Similar decisions enable timely actions by forest protection and supervision specialists, preventing the spread of plant diseases, forest fires, and unauthorized logging in monitored forests and protected areas.

Attention to climate change and its impact on natural ecosystems intensifies daily. The issue of comprehensive monitoring of forest resources is one of the most pressing today, as evidenced by global statistics. Published materials by the United Nations [1] discuss the increasing number of forest fires, which raises concerns due to its association with global climate change and land-use practices. In addition to anthropogenic and human factors, droughts, warming, decreased relative humidity, lightning, and strong winds prolong periods of extreme heat and the wildfire season. According to a report by the United Nations Environment Programme (UNEP) [1], the frequency of forest fires is projected to increase by 14 percent by 2030, 30 percent by mid-century, and 50 percent by the end of the current century. Those metrics indicate that the world faces a severe environmental challenge that requires the development of

practical solutions to prevent the increase in the number and intensity of forest fires. These statistics underscore the importance of forest resource monitoring and the availability of real-time information about forest conditions, especially during periods of high fire risk. Forest fires cause immense damage and threaten human life and health. Monitoring meteorological conditions that affect forest health, along with changes in other physical processes and climatic indicators, is of paramount importance, not only in Russia but globally.

An analysis of current monitoring systems in Russia and beyond reveals a significant limitation. Most of these systems are based on empirical or semi-empirical models, which means they lack a solid physical basis and typically only consider meteorological data. They need to adequately account for natural factors and anthropogenic impacts, highlighting the need for more comprehensive and accurate monitoring systems.

Among the most well-known fire danger monitoring systems are the Canadian Forest Fire Danger Rating System (CFFDRS), the American National Fire Danger Rating System (NFDRS), the Australian National Fire Behaviour Prediction System (NFBP), and Russian methodologies. The CFFDRS is based on the analysis of an extensive amount of statistical data, which has been used to create tables showing the dependence of fire danger on various factors [2]. In addition to Canada, it has been adapted for use in New Zealand, Fiji, Mexico, Alaska, Florida, and Southeast Asian countries. The NFDRS has a logical structure and uses a mathematical model to assess the influence of various factors and conditions on the occurrence and spread of fires. It includes 20 parameters for assessing fire danger and 13 for predicting fire behavior. The system consists of large-format tables where input and output data (both tabular and graphical) are handled using a systematic, organized, and simple computational mechanism. The Canadian and American systems are very similar in structure, approaches, and principles of constructing the fire danger index [3,4]. However, their use in other countries is not feasible without extensive preliminary work to determine numerous empirical coefficients. The lack of physically meaningful values for specific constant coefficients limits the range of input parameter values and the application of these methods under different initial conditions. The Australian system for assessing forest and grassland fire danger widely uses McArthur's indices [5,6], developed and tested in southeastern Australia. This system allows for relatively rapid estimation of natural fire spread parameters.

A key drawback of the current monitoring systems is their need for more standardization. The absence of a universal approach to their design means these systems can only be used globally with prior adaptation. They rely on empirical data specific to certain types of vegetative fuel and climatic conditions, which vary significantly across different

regions. Furthermore, most systems are prone to inaccuracies and errors due to the mathematical models they use. The primary disadvantage of these systems is their failure to address the actual causes of natural fires.

II. PROBLEM STATEMENT

In Russia, fire danger assessment based on weather conditions is performed according to the comprehensive indicator developed by V.G. Nesterov [7]. This indicator uses data from regional meteorological stations and is determined through air temperature, dew point at specific hourly intervals of local time on the current day, and a precipitation accounting coefficient. This indicator cannot be applied to vast, sparsely populated areas with sparse or absent meteorological station networks. Therefore, the results of such forecasts need to be supplemented by considering actual physical processes, such as evaporation and condensation, vapor pressure deficit (VPD), drought index, and others. The general mathematical model of forest fires proposed by A.M. Grishin [8], which considers the laws of conservation of mass, momentum, and energy, as well as physicochemical processes, describes the processes of ignition and combustion development in all forest layers and considers the mutual influence of processes in the atmospheric boundary layer, forest canopy, and the underlying surface. This approach's advantage lies in applying the latest advances in continuum mechanics and aerothermochemistry. The concepts incorporated into this model are successfully used not only in Russia.

Despite a considerable number of studies dedicated to examining the ignition and spread of natural fires [9,10,11], the problem of accurately and timely predicting the occurrence and spread of natural fires and effectively combating them remains unresolved. This underscores the urgent need for new approaches and solutions in this field.

In this context, monitoring the physical parameters and meteorological conditions that affect the health of Russian forests, which are threatened by changing climatic indicators, becomes particularly significant. An analysis of existing technical solutions has revealed that many monitoring systems are limited to providing general meteorological data without considering specific indicators crucial for assessing the future risks of drought conditions and fires.

III. METHODOLOGY

3.1 Features of data collection

The developed product is an information-analytical system based on an unmanned aerial vehicle (UAV) that collects data through aerial photography. The boundaries, type, and composition of the depicted forest are determined from the photographs. Images captured by sensors of various sensitivities are fed into a neural network and processed according to a specified algorithm. The output layers provide

forecasts regarding the type of forest, its approximate composition, and its location determined by UAV coordinates. Currently, the main competitor to this solution is satellite image processing, which has limitations and drawbacks. Obtaining and processing up-to-date satellite images requires significant time resources. This method of monitoring forest resources is not universal and only allows for detecting fire sources. Furthermore, forecasting fire occurrences with cartographic accuracy using satellite images is challenging. Satellite images contain high noise and disturbances such as clouds, image stitching, and filtering based on the color spectrum, requiring additional processing to prepare them for analysis. Developments in improving satellite image processing algorithms need to address the timeliness issue of data acquisition. Such approaches use algorithms to detect changes in individual image sections and still require initial image processing to remove noise and disturbances. This mapping type has limitations: the swath width of satellite image capture is approximately 15 km, the distance to the ground is about 700 km, and the best resolution achieves 30 cm to 5 m per pixel. It is anticipated that UAVs can more accurately assess the probability of ignition based on media content and identify potential fire boundaries and their coordinates. The camera resolution of UAVs can reach up to 4k format, with a ground distance of about 50 m, providing ≥ 3 cm per pixel. Improving the monitoring results of forest areas and achieving this level of accuracy can be accomplished using UAVs flying along a planned route for up to 10 hours and analyzing the captured media content upon landing using machine learning tools. In UAV-acquired images, all objects (tree stands) are distinguishable, simplifying the process of marking the dataset for forest/tree recognition.

Many forests monitoring systems, using high-resolution Landsat-8 satellite imagery, have enhanced a deep learning model based on U-Net by integrating Spatial Pyramid Pooling (SPP) modules to improve forest boundary segmentation. Their experiments demonstrated significant increases in accuracy and performance metrics such as IoU, F1-score reaching results of 86.71%, 75.59%, and 82.88%, respectively. This system holds promise as a tool for governmental and private institutions in monitoring and tracking changes in forested areas. However, its development is focused on analyzing imagery at a large scale of tens of kilometers, enabling conclusions only about the overall state of forested regions without delving into specific details [12].

The UAV returns to its base by performing aerial monitoring along specified flight coordinates, where experts receive data. Current data includes actual flight coordinates, readings from thermometers, humidity sensors, barometers, video camera data, and shooting angles. Modules within the information-analytical system process these data, analyzing specific forest parameters as depicted in Figure 1

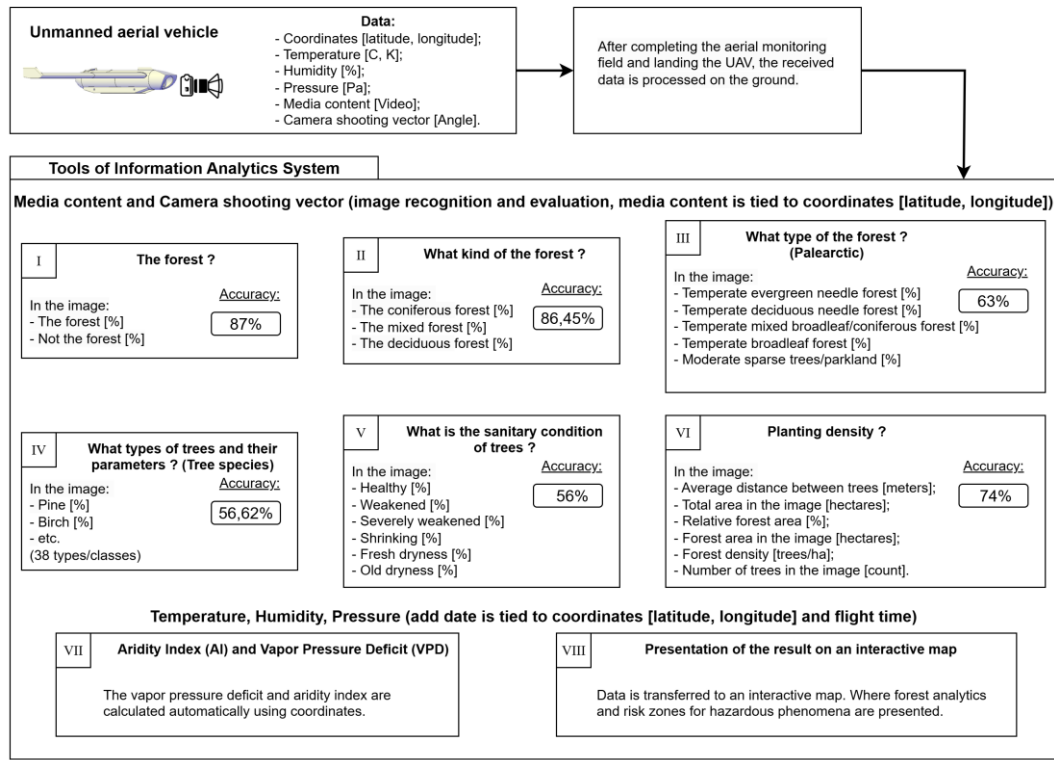


Fig. 1. Flowchart of Data Collection and Processing.

Based on the collected data, the following metrics are determined: drought index, vapor pressure deficit, tree density, tree height estimation, radius of tree root systems, and others. After processing, the data are visualized on an interactive map.

3.2 Deep Learning Approach

Various studies use neural networks to focus on forest segmentation, analysis, and inventory. To train neural networks for segmentation and classification tasks based on digital imagery, diverse methods for data collection and annotation are employed. Ensuring the efficiency of training and enhancing the accuracy of segmentation algorithms requires high-quality preparation of raw data and diversifying their range. Following meticulous preparation and annotation of the dataset, the next step in improving model performance involves applying data augmentation techniques. These

methods aim to increase the volume and diversity of the training set by introducing modifications to the original images, thereby reducing overfitting and enhancing the model's robustness against variations in input data [13]. The combination of augmentation methods significantly improves the accuracy of forest segmentation. Convolutional neural networks (CNNs) are employed in the implemented system to extract informative features from images or other input data before using them for segmentation tasks. Architectures such as VGG16 [14] and ResNet [15] have been selected for their high accuracy, fast convergence, and ability to operate effectively with limited data and computational resources. This approach enables the detection and segmentation of objects in the image. It facilitates a deeper analysis of each tree's type, a crucial step for a more comprehensive and accurate assessment of forested areas, as depicted in Figure 2

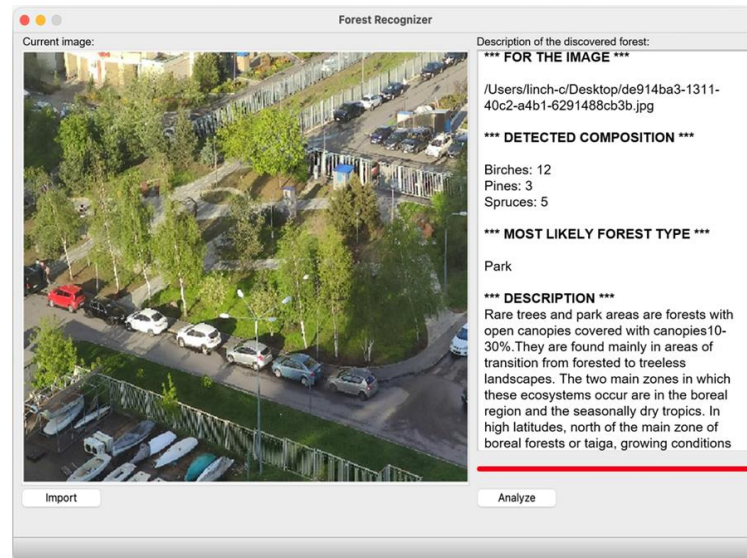


Fig. 2. Model output.

The training of the neural network was accelerated by leveraging pre-trained weights from the ImageNet dataset [16], a method that significantly enhances the efficiency of the training process. Preparing datasets for training involved

formatting the data appropriately and splitting it into training, validation, and testing sets in an 8:1:1 ratio. This separation helped optimize the training process and model evaluation. Input and output data are depicted in Figure 3.

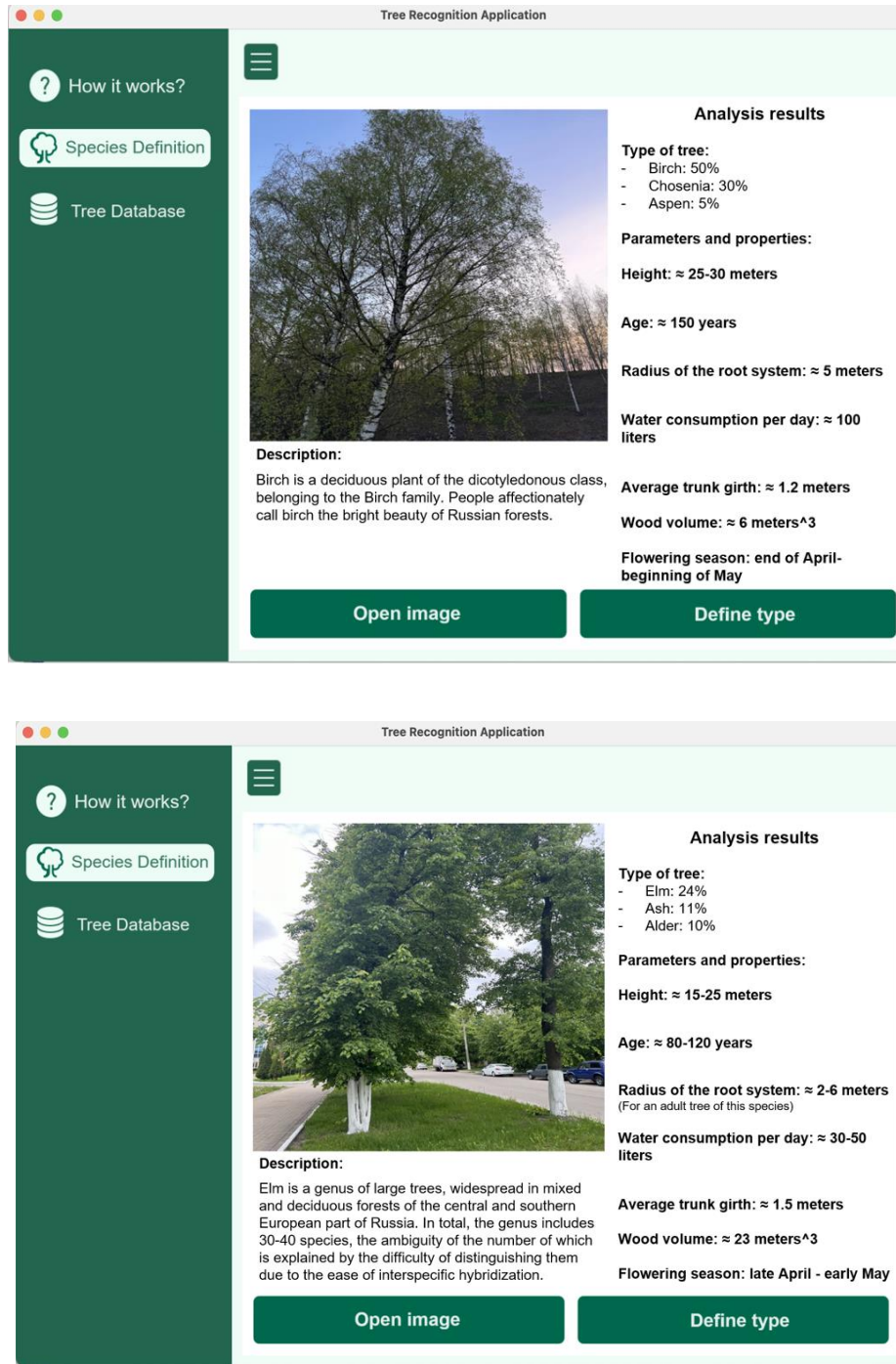


Fig. 3. Tree species recognition results in the information analytics system.

Based on the testing results on the designated dataset, the segmentation model achieved a 53% Intersection over Union (IoU) score [17], indicating the adequacy of the developed methodology for segmenting forested areas. The classification model demonstrated an accuracy of 74% on the test dataset. These outcomes enable efficient automation of processes involving forest type identification, tree class determination, density assessment, average tree spacing, tree count estimation, and evaluation of forest health.

3.3 Analysis of climatological parameters: vapor pressure deficit (VPD) and aridity index (AI)

The parameters such as Vapor Pressure Deficit (VPD) and Aridity Index (AI) are crucial for understanding and predicting natural processes, including forest fire spread, plant growth, and development, as well as their impact on climate and atmospheric phenomena. Based on the research findings, a model for VPD has been developed, as represented in Formulas 1 – 3, to determine the vapor pressure deficit.

$$e_{sat} = 6.112 \times \exp\left(\frac{17.67 \times \text{temperature}_c}{\text{temperature}_c + 243.5}\right) \quad (1)$$

$$e_{act} = \left(\frac{\text{relative_humidity}}{100} \right) \times e_{sat} \quad (2)$$

$$vpd = e_{sat}(T) - e_{act} \quad (3),$$

where e_{sat} — is the saturated vapor pressure, and e_{act} — is the actual vapor pressure.

The calculation of saturated vapor pressure utilizes the Magnus equation to estimate the pressure of saturated vapor over a flat surface of water at a given temperature in degrees Celsius. The calculation of actual vapor pressure indicates the portion of saturated vapor that is present in the air at a specific humidity level. The VPD index is critically essential for fire safety, as high VPD values increase the likelihood of fire ignition and spread.

According to research published in the Journal of Student-Scientists' Research [18], forecasts based on VPD

were found to be more accurate compared to other indices such as the Fire Weather Index (FWI). Additionally, climate change influences the frequency and intensity of fires, driven by increases in VPD. Research by Abatzoglou and Williams [19] demonstrated that climate changes lead to higher VPD values, thereby increasing the likelihood of forest fires. The aridity index [20] is used to assess the level of aridity in regions based on the ratio of precipitation to potential evaporation. The aridity index is calculated according to Formula 4.

$$AI = -10 \times precip_{mm} + 1800 \quad (4),$$

where $precip_{mm}$ — the amount of precipitation in millimeters.

This index allows for the evaluation of long-term trends in changes in the moisture level of territories, which is essential for assessing the risks of wildfires. Climate data influencing forested areas were visualized using an interactive map [21], as shown in Figure 4.

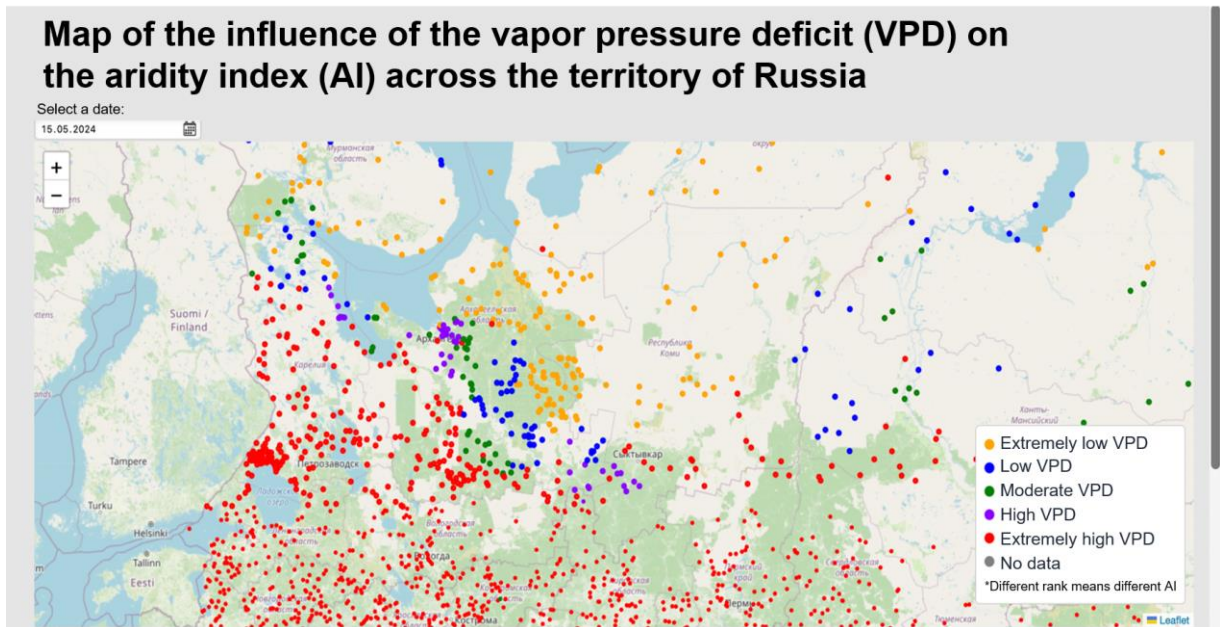


Fig. 4. Visualization of the impact of Vapor Pressure Deficit (VPD) on the Aridity Index (AI).

IV. ARCHITECTURE OF THE INFORMATION ANALYTICS SYSTEM

The key functionality of the information-analytical system is the ability to track meteorological changes and analyze them based on archival data, enabling users to

observe the current situation and analyze trends over time. The system provides data for all major cities and regions collected through weather service APIs, updated in real-time through built-in asynchronous updating mechanisms. The technical diagram is depicted in Figure 5.

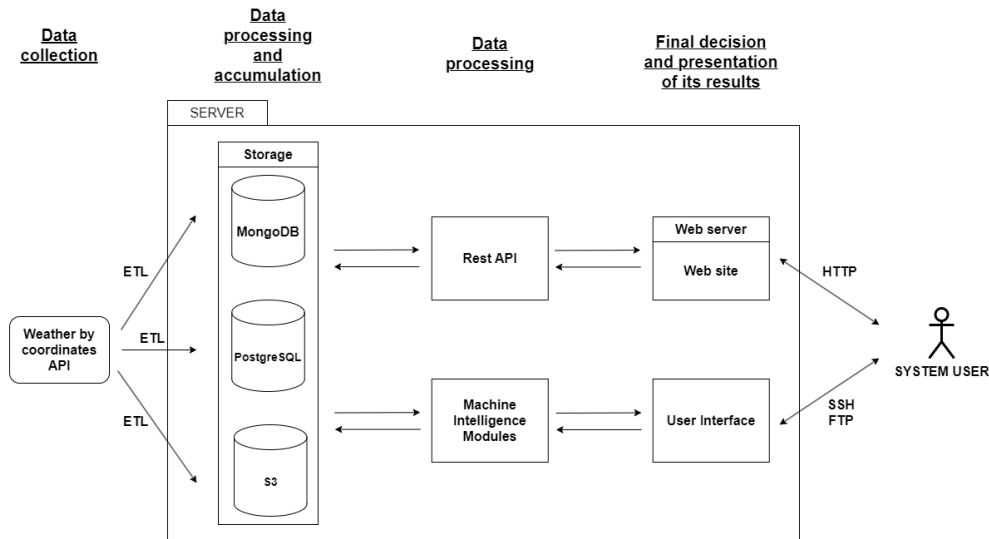


Fig. 5. Structural diagram of the information analytics system.

V. CONCLUSION

The research showed that using UAVs allows for the most effective collection of critical data for subsequent analysis of forest ecosystems. It presents an original approach involving the application of deep neural networks to analyze tree density and other forest characteristics using images of Russian forest territories. This approach encompasses data collection, markup, and preparation for neural network training, selecting suitable architecture and segmentation algorithms, and model training on the training dataset. The represented machine learning methods help enhance the accuracy of recognizing surveyed forest features.

An information-analytical system has been developed, the architecture of which is depicted in Figure 5. Based on collected and preprocessed data on forest ecosystems, this system enables classification functions of forests according to required parameters and properties such as average tree height, age, root system radius, water consumption per day, forest density, and stand health. The system's user interface supports the working cycle with computed forest parameters, utilizing stored neural network models. Monitoring results and analyses of forest ecosystem conditions can be visualized using an interactive map of the surveyed area.

Thus, the proposed methodology and the obtained results are theoretical concepts and practical tools that can be applied in natural resource monitoring and management. They can also serve as a basis for further scientific research to study forest ecosystem conditions more thoroughly. The potential for future research to focus on developing an approach to forecasting fire hazards based on the collected and processed data is inspiring, opening new possibilities for forest management.

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Development of a Tool for Forest Type Recognition for Mapping Using Machine Learning Methods

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Abstract — This paper proposes a method for analyzing images obtained from UAVs using a combination of convolutional neural networks (CNNs) and classical machine learning methods. Convolutional neural networks are employed to analyze object types and solve the classification task to obtain the forest composition in the image, while machine learning methods are applied to determine the forest type based on the identified composition. The article discusses data collection and processing challenges, as well as the advantages and disadvantages of various CNN architectures. The proposed combination allows for solving a specialized task, expanding the capabilities of the computer vision system, ensuring reliability and high operational speed. Potential improvements to the obtained solution are also considered.

Keywords — *Forest Type Recognition, UAV (Unmanned Aerial Vehicle) Imagery, Machine Learning, Image Segmentation, Forest Mapping, Convolutional Neural Networks (CNN), ResNet18, YOLOv8, Data Augmentation, Decision Tree Classifier, Transfer Learning, Forest Monitoring, Environmental Analysis, Remote Sensing, GIS (Geographic Information System), Aerial Photography, Tree Species Classification, Neural Networks, Object Detection, Image Classification.*

I. INTRODUCTION

The issue of wildfires is one of the most urgent challenges facing the global community today, as demonstrated by statistics collected from around the world. According to an article published on the United Nations News website [1], the frequency of forest fires is increasing alarmingly. This trend is directly linked to global climate change and evolving land-use practices. A recent report by the United Nations Environment Programme (UNEP) projects that the frequency of forest fires will rise by 14% by 2030, by 30% by mid-century, and by as much as 50% by the end of the century. These figures highlight the pressing need for timely and accurate information about forest conditions during periods of elevated fire risk. This need creates an urgent demand for effective and rapid solutions that provide up-to-date data about forest areas across diverse regions, empowering biologists and forestry professionals to take timely actions to prevent the spread of wildfires, mitigate vegetation and soil diseases, and combat illegal logging activities.

In response to this challenge, this work focuses on developing a system for determining forest types based on images captured by unmanned aerial vehicles (UAVs). Understanding the distribution of forest types is critical because different types exhibit varying levels of flammability and ignition risk, influenced by factors such as weather conditions and proximity to other vegetation types. Thus, having accurate and detailed information about forest type distribution on a map, including the relationships between adjacent forest types, is crucial for effective wildfire prevention and forest management.

The primary goal of this research is to create a software-analytical system for the automated classification of forest types from UAV imagery. To achieve this, several tasks must be addressed, including collecting and analyzing datasets, designing and training machine learning models to classify forest and tree types, and developing an intuitive tool to enable users to apply these methods effectively. This effort will result in a hardware-software complex that integrates UAV technology for data collection through aerial photography with a neural network capable of analyzing these images. The neural network will process inputs captured by sensors with various spectral sensitivities, identifying forested areas' boundaries, types, and compositions while determining their geographic locations based on the UAV's known coordinates.

Although current advancements in satellite-based image processing [2] have improved our ability to monitor forests, these methods face limitations in acquiring real-time, high-resolution data. Satellite imagery often requires preprocessing to remove noise and interference, and it struggles to provide rapid updates in areas affected by cloud cover or rapid ecological changes. The proposed UAV-based system addresses these shortcomings by enabling faster data acquisition and high-resolution analysis. Specifically, this research focuses on developing algorithms for detecting changes in specific areas of images captured by UAVs, which will significantly enhance the timeliness and accuracy of forest monitoring efforts.

The relevance of this work lies in its ability to enable the classification of forest types using UAV imagery, which will facilitate the analysis and monitoring of changes in forest conditions caused by climate change, wildfires, logging, and other factors. Additionally, integrating UAV technology into forest monitoring frameworks will improve classification accuracy, simplify mapping, and reduce associated costs. A review of recent literature, including a study on the application of machine learning for forest mapping [7], reveals a lack of developments that utilize UAV imagery for this purpose. The study's authors noted that incorporating UAV imagery into forest-type classification could substantially improve mapping accuracy, further emphasizing the importance of this research.

In conclusion, this work aims to contribute a transformative approach to forest monitoring by leveraging UAV technology and advanced machine learning methods. The proposed system can address critical gaps in existing methodologies, providing actionable insights for wildfire prevention, forest conservation, and sustainable land management. By combining innovative technology with robust analytical tools, this research aligns with global efforts to protect ecosystems and mitigate the impacts of climate change.

II. REVIEW OF EXISTING APPROACHES

Forest mapping, the process of creating detailed representations of forested areas, captures the structure, composition, and key characteristics of forest ecosystems. This procedure plays a vital role in monitoring and managing forest resources, ensuring environmental protection, and promoting sustainable forest utilization. Several methodologies are commonly employed for forest mapping, including manual techniques, satellite imagery, and UAV-based imaging.

The manual method involves on-site fieldwork to observe and record forest composition and characteristics. This approach includes several stages: preparation, field data collection, and analysis. The preparation phase involves studying existing maps, analyzing topographic and landscape features, and defining trip objectives. During field visits, tools such as compasses, GPS devices, and rangefinders are employed to orient and mark significant objects. Observations focus on identifying tree species, measuring their dimensions, evaluating forest structure, and collecting undergrowth, plant, and soil samples. Data are meticulously documented in forestry maps or notebooks, supplemented by photographic evidence. The final phase involves processing the collected data using specialized software to produce comprehensive maps. While this method excels in delivering high accuracy and detailed results, it is labor-intensive, time-consuming, limited in geographic scope, and susceptible to human error in data interpretation.

Satellite imagery offers an alternative approach, providing data captured from orbital devices equipped with advanced cameras and sensors. Geographic information systems (GIS) and other specialized software are used to process these images. This method offers several advantages. First, its wide coverage allows for the mapping of large and remote areas that are otherwise inaccessible using ground-based techniques. Second, its high update frequency enables near-real-time monitoring of changes within forested regions. Third, the use of multispectral imagery, including infrared data, allows for the detailed analysis of vegetation, water resources, and other environmental features. However, satellite imagery also has limitations. The resolution of satellite images often lacks the detail required for applications involving smaller objects or tasks demanding high precision. Additionally, data acquisition is highly dependent on weather conditions, with cloud cover, precipitation, and other atmospheric factors frequently obstructing image capture.

UAV (unmanned aerial vehicle) imaging has emerged as a promising solution for forest mapping. Drones equipped with high-resolution cameras, infrared sensors, and other spectral imaging tools capture data from varying altitudes and angles, offering unparalleled flexibility. UAVs provide several advantages. They deliver high-resolution, detailed imagery that meets the precision requirements of complex mapping tasks. The maneuverability of UAVs, combined with their ability to adjust altitude and angles in real time, enhances their adaptability to diverse objectives. Unlike satellite methods, UAVs can operate in most weather conditions and during any time of day, ensuring reliable data collection. However, UAVs are not without their challenges. Their limited flight range and battery life constrain their utility over expansive areas, necessitating multiple flights for larger regions.

III. TYPES OF IMAGES FOR MONITORING FOREST CONDITIONS

Despite the limitations of satellite data, advancements in algorithms for detecting changes in forest cover continue to emerge. Article [8] presents an algorithm for identifying deforestation by analyzing paired satellite images captured at different times. Neural networks process these images to generate a binary mask indicating areas of deforestation. Using 109 image pairs, three neural network models—ResNet-34+U-Net, SegFormer_b5, and SegNeXt_1—were evaluated based on the Sørensen coefficient, accuracy, recall, and F-measure. The SegNeXt_1 model achieved the highest Sørensen coefficient (0.84) and recall (0.80), while ResNet-34+U-Net excelled in accuracy (0.71) and F-measure (0.74).

Article [9] highlights modern satellite-based forest classification techniques using machine learning. Key advancements include hyperspectral imaging, which achieved 87% accuracy in mapping Italian forests when combined with a digital elevation model; high-resolution object-based classification, with accuracy between 76% and 85%; and LiDAR, which provides canopy density and biomass measurements with up to 91% accuracy. Combining multispectral data with LiDAR using Support Vector Machines (SVM) further reduced uncertainty. However, these methods face challenges, such as mixing canopy and ground information, limited hyperspectral and LiDAR data coverage, high costs, and reduced efficacy under cloudy conditions.

Article [10] underscores the importance of monitoring forest species but critiques satellite-based methods' inability to distinguish tree species accurately. Ground-based methods, including manual classification and standard photography, are more accurate but demand significant time and resources. UAVs offer a practical compromise, combining high-resolution imagery with reduced costs. Rain remains the primary operational challenge, though waterproof UAVs [13] can mitigate this issue. Unlike satellites, UAVs require fewer restrictions, enhancing their adaptability.

In [11], a LiDAR-based mapping system using GEDI data is introduced. Challenges with satellite image processing are addressed through four filters: eliminating images with incorrect amplitude and laser shot energy, daytime images (to avoid solar noise), highly heterogeneous vegetation, and poor geolocation. Only data with less than 10% cloud cover and stable humidity are used, illustrating the complexities of forest classification using satellite data. Article [12] notes that a significant percentage of satellite data is unsuitable for forest classification, limiting accuracy. During wildfires, detection via satellite is constrained to smoke visibility, and stringent image requirements further reduce reliability. UAVs, with fewer restrictions, are proposed as a superior alternative for accurate canopy and forest-type classification.

Article [14] describes forest classification using 1-meter resolution satellite images, notably lower than the 4K resolution targeted in this project. Random Forest (RF) machine learning achieved classification accuracy ranging from 68% to 95%, depending on the region. RF may be considered in this project. Article [15] highlights the advantages of combining UAV and satellite data, as UAVs provide more detailed and up-to-date imagery but require preprocessing to correct lens distortions.

UAV applications for vegetation diagnostics are explored in [16], which proposes a modified U-Net architecture (M-CR U-Net) with OVCS post-processing for early detection of

stem rot disease (SRD) in oil palms. Article [17] demonstrates UAV and machine learning models for estimating sorghum's leaf area index (LAI). Field experiments used multispectral and thermal UAV imagery over two years, testing five machine learning algorithms (K-NN, ETR, XGBoost, RF, SVR). Combinations of NDVI, canopy height, SAVI, and GNDVI indices were most effective. Results confirmed that UAV-based data and ML models offer a cost-efficient, scalable solution for precision agriculture, with implications for climate modeling and crop management.

Article [18] reviews UAV applications in precision agriculture (PA), emphasizing increased productivity and reduced environmental impact. Article [19] discusses UAV-based pine wilt disease (PWD) detection, which is critical for controlling its spread. Faster R-CNN and YOLOv3 models were tested, achieving similar accuracy (0.602–0.64), with YOLOv3 noted for speed and compactness. Article [20] proposes a multi-sensor UAV system for rapid, high-accuracy PWD diagnosis, surpassing traditional microscopy-based methods.

Low-cost UAV applications are reviewed in [21], which mapped palms in a 135-hectare Amazon area. Three species were manually outlined: *Attalea butyracea*, *Euterpe precatoria*, and *Iriartea deltoidea*. *E. precatoria* was classified with the highest accuracy. Article [22] examines UAV-based identification of *Hovenia dulcis* in Brazil, employing Random Forest (91.5% training, 90.91% testing accuracy).

Multispectral imaging combined with UAVs is addressed in [23], emphasizing their role in agriculture for assessing crop health and automating field management. Article [24] discusses advanced technologies in Russian forestry, including UAVs for pest detection, firefighting, and illegal logging monitoring. Article [25] emphasizes preprocessing satellite images before using neural networks to enhance forest management efficiency. Article [26] reviews methods for detecting forestry roads using remote sensing and ML, including the MapFlow plugin for QGIS, useful for fire modeling and equipment deployment.

Article [27] explores forest stand mapping with UAVs and laser scanning, particularly at the forest-tundra ecotone sensitive to climate change. Digital canopy models and tree crown boundaries were generated, demonstrating the method's precision. Article [28] reviews historical aerial mapping techniques and their integration into natural resource surveys.

Recent advancements in deep learning are highlighted in [29], where convolutional neural networks (CNNs) achieved over 90% accuracy in tree crown detection. Article [30] describes YOLOv4-Lite for urban tree crown detection, showing a 36.2% accuracy improvement compared to older methods. Article [31] uses UAVs for early-stage weed mapping via Object-Based Image Analysis (OBIA) to optimize herbicide application.

Applications of neural networks for ecological risk assessment are discussed in [32], where ML and geoinformation analysis were combined to predict contamination risks in the Khanty-Mansi region. Articles [33] and [34] compare ML models like SVM, RF, and Stochastic Gradient Boosting (SGB) for vegetation classification, noting varying accuracy based on input data and collection conditions.

Further articles explore UAV uses for complex tasks like mapping cocoa forests [35], tobacco plant classification [36],

and tree species identification using 1D-CNN models [37]. Article [38] reviews hyperspectral satellite data for forest classification using VGG19 + ResNet50 models, achieving 93-100% accuracy. Article [39] highlights UAV advantages for real-time monitoring, surpassing satellite imaging in detail and cost-effectiveness.

As noted in [40], segmentation should precede classification for optimal results. While models like Segment Anything excel in segmentation, they occasionally over-segment objects based on visual variations. Article [41] critiques UAV costs for large-scale surveys but suggests solar-powered UAVs capable of extended flights as a feasible solution. Articles [46] and [47] evaluate UAV costs and resolution, noting that advancements and mass production may reduce current expenses, making UAVs increasingly preferable for forest monitoring.

This project aims to integrate the best-reviewed methods and develop software for forest-type classification from UAV imagery. After segmentation, the software will classify regions into coniferous, deciduous, and non-forest categories, determining forest types based on proportional composition and a comprehensive glossary. The most suitable classification model will be selected through rigorous testing.

IV. ARCHITECTURE DESCRIPTION

UAV images were chosen for data collection due to their numerous advantages over satellite imagery. UAVs provide significantly higher resolution, enabling detailed and accurate data capture of forest areas. This precision is crucial for vegetation analysis and assessing specific forest characteristics. Additionally, UAVs offer extensive control over the imaging process, allowing users to adjust height, camera angles, and proximity to objects. This flexibility supports precise customization for project requirements, including targeting specific areas and adapting to dynamic conditions. Furthermore, UAVs facilitate real-time image acquisition, enabling prompt responses to changes in forest areas, such as monitoring wildfires or disruptions in forest cover.

Once data is collected, machine learning methods are employed for automated classification, leveraging their capacity to process large datasets efficiently. Machine learning algorithms can identify intricate patterns and features in forest images, making them ideal for forest-type classification. Algorithms trained on substantial datasets achieve high accuracy, critical for distinguishing tree and forest types. They enable rapid data analysis, essential for real-time decision-making, while automation minimizes human intervention, reducing labor, time, and costs. Moreover, machine learning models adapt to new data and changing conditions, ensuring reliability in dynamic forest environments.

To address the challenge of limited datasets, transfer learning was adopted for image classification tasks. Transfer learning accelerates training by utilizing pre-trained models, enhancing accuracy even with smaller datasets. This is particularly beneficial when UAV-derived data is scarce. For tree-type determination, ResNet18 was selected due to its effectiveness in computer vision tasks. It is easy to train, resource-efficient, and performs well on small datasets, making it ideal for forest classification. Before classification, segmentation was applied to the images, isolating areas of interest and improving analysis accuracy. Studies confirm that segmentation enhances model performance by accurately distinguishing trees and vegetation.

employed with transfer learning and the AdamW optimizer. To mitigate overfitting issues, the ResNet18 model was selected for the more complex task of classifying five distinct forest types. For tree segmentation and detection, the YOLOv8 model was utilized. It underwent extensive testing and validation, demonstrating high effectiveness in processing UAV imagery.

A decision tree algorithm was used to classify forest types based on tree composition within each image. A dedicated dataset was prepared, including quantitative information about the prevalence of different tree species in the images. This facilitated accurate forest-type classification by analyzing stand composition. To enhance training set quality, further data augmentation was carried out, balancing the classes and reducing overfitting risks. The decision tree model was optimized through hyperparameter tuning, cross-validation, and grid search techniques. The final model was rigorously tested and validated to ensure reliability and high accuracy.

A graphical user interface (GUI) was developed for the software to provide a user-friendly experience. Built using the PySide6 framework, the interface ensures functionality, intuitiveness, and accessibility. Key features include uploading images, initiating analysis, and displaying classification results. The GUI streamlines interaction with the software, enabling efficient operation for users without technical expertise.

The software system underwent a complete development lifecycle, including design, implementation, and testing. All modules were developed and tested, with comprehensive documentation created to support the entire software complex. This documentation ensures maintainability and scalability, enhancing the software's usability and adaptability for future improvements.

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Mathematical Model of Electronic Document System Dynamics for Identifying Business Process Bottlenecks

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Abstract—The transition to electronic document management systems has become a critical strategic initiative for modern organizations. Measures taken to organize electronic document flows in a rational manner are particularly relevant, as their imperfections can lead to significant losses for organizations. A well-structured approach is proposed to analyze existing business processes, with attention to identifying potential bottlenecks through modeling. In particular, a dynamic system model for electronic document management based on a Markov scheme is introduced. The innovative approach is shown to conduct detailed cost assessments of both productive and non-productive document states, offering valuable insights into system efficiency.

Keywords—Markov process, electronic document, electronic document management system, security metric

I. INTRODUCTION

Numerous large organizations are known to actively pursuing programs in the field of digital transformation, including initiatives focused on the implementation of various electronic document management systems (EDMS) [1, 2].

For the purposes of the research, document flow is understood as the sequence of document movement through various organizational units and executors, starting from the moment they are received (or created) until their execution is completed (or they are sent outside the organization).

For an organization that has integrated an EDMS into its IT landscape, the analysis of electronic document (ED) circulation becomes exceptionally important. As practical experience from several projects has shown, a significant number of ED routing paths are implemented in EDMS across different organizations, with thousands of EDs being processed monthly. Due to inadequacies in processes for manageable information flows (MIF), circumstances may arise where a part of EDs is not processed properly within the expected timeframe. Such disruptions can inflict considerable losses, a risk that becomes all the more significant in the corporate information systems of medium-sized and large organizations.

The successful operation of an EDMS is largely determined by how business processes for ED processing are organized, highlighting the need to optimize MIF processes and create a mathematical model of ED movement.

II. RELATED WORK

By the present time, a sufficient number of methods have been developed for modeling EDM — from set-theoretical and graph-theoretical approaches to Petri net-based models [3-21]. The comparative characteristics of different modelling notations are presented in Table 1.

TABLE I. COMPARATIVE ANALYSIS OF MODELLING APPROACHES

Approach	Advantages	Disadvantages
Set-Theoretic Approach: Set Theory	Description and formalization of the dynamic model of ED processing	Limited practicality, focused on static rather than dynamic indicators
Graph-Theoretic Approach: Graph Theory	Possibility of identification of critical nodes and cycles; flexibility when changing business processes	Labor-intensive analysis with a significant number of vertices and edges; limitations in analyzing probabilistic processes and accounting for uncertainties
Graph-Theoretic Approach: Petri Nets	Description and formalization of the dynamic model of ED processing; possibility of identification of cycles and incorrect transitions	Limitations in analyzing probabilistic processes and accounting for uncertainties; difficulties in scaling; difficulties in interpreting results
Probabilistic-Parametric Approach: Petri-Markov Nets	Description and formalization of the dynamic model of ED processing; ability to analyze dynamic and temporal characteristics; accounting for the probabilistic nature of processes	Difficulties in scaling to thousands of homogeneous instances of ED (in aspects of system dynamics); inability to analyze continuous random variables
Mathematical Apparatus of Decision Tables	Description and formalization of the dynamic model of ED processing; simplicity in representing complex logic; flexibility when changing business processes	Limited practicality, focused on static rather than dynamic indicators; limitations in analyzing probabilistic processes and accounting for uncertainties
Agent-Based Approach	Flexibility when changing business processes possibility of identification of critical nodes and cycles; ability to analyze rare events	Labor-intensive and resource-intensive development; high demands on computing resources

While existing electronic document management (EDM) modeling approaches provide formal ED processing frameworks with good flexibility, they lack adequate capabilities for analyzing probabilistic processes and uncertainty factors. Stochastic methods are better suited for EDMS modeling since ED processing parameters are inherently probabilistic. However, considered probabilistic

approaches have significant limitations in aspects of system dynamics.

III. PROBLEM STATEMENT

Within the technological chain of ED processing, the functional model of an EDMS in the IDEF-0 (Fig. 1) notation is adopted as the methodological foundation in this research.

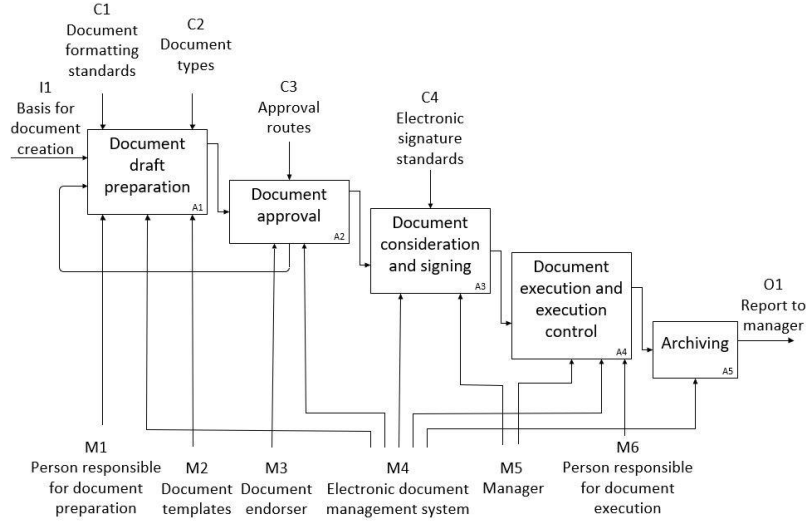


Fig. 1. Functional model of an EDMS in the IDEF-0 notation

A mathematical model for EDM needs to be developed that balances the EDMS's probabilistic nature with manageable computational complexity. The model should capture ED processing procedures while incorporating uncertainty factors, enabling multi-criteria optimization

IV. METHODS

A. Markov Process Scheme

ED movement in EDMS can be modeled as state transitions triggered by event flows. This process is effectively represented using discrete Markov random processes with continuous time, as ED transitions between states occur randomly and are driven by event intensities.

Based on the IDEF-0 functional model (Fig. 1), a single ED processing in EDMS is represented by a state graph (Fig. 2), showing possible transitions between ED states.

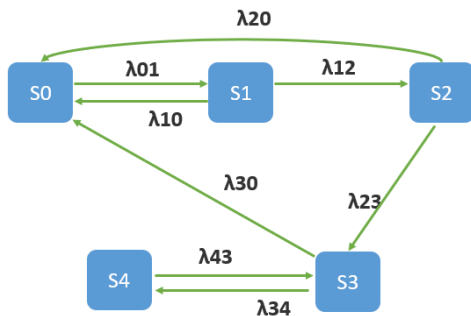


Fig. 2. State graph of ED lifecycle

In Fig. 2, the preparation of ED draft is designated as S_0 , ED approval – S_1 , ED consideration and signing – S_2 , ED execution and monitoring of execution – S_3 , ED archiving – S_4 . Due to the specific requirements for processing different types of EDs, it is advisable to conduct research for each ED type separately.

The probability $p_i(t)$ of the i^{th} state of an ED is determined by the system of Kolmogorov-Chapman differential equations (1):

$$\begin{cases} \frac{dp_0(t)}{dt} = -p_0(t)\lambda_{01} + p_1(t)\lambda_{10} + p_3(t)\lambda_{30} + p_2(t)\lambda_{20} \\ \frac{dp_1(t)}{dt} = -p_1(t)\lambda_{10} - p_1(t)\lambda_{12} + p_0(t)\lambda_{01} \\ \frac{dp_2(t)}{dt} = -p_2(t)\lambda_{23} - p_2(t)\lambda_{20} + p_1(t)\lambda_{12} \\ \frac{dp_3(t)}{dt} = -p_3(t)\lambda_{30} - p_3(t)\lambda_{34} + p_2(t)\lambda_{23} + p_4(t)\lambda_{43} \\ \frac{dp_4(t)}{dt} = -p_4(t)\lambda_{43} + p_3(t)\lambda_{34} \end{cases} \quad (1)$$

where λ_{ij} is the intensity of transition from the i^{th} state to the j^{th} state.

The normalizing condition is defined by the expression (2):

$$p_0(t) + p_1(t) + p_2(t) + p_3(t) + p_4(t) = 1 \quad (2)$$

B. Method of Dynamics of Averages

For systems processing large volumes of ED, the method of dynamics of averages can be applied to EDMS modeling. The EDMS operation is characterized by interactions between homogeneous ED groups, where homogeneity refers to identical transition intensities and states within the state graph [22]. The Kolmogorov-Chapman equations are then used to calculate the average numbers of EDs in each state (3):

$$\begin{cases} \frac{dm_0(t)}{dt} = -m_0(t)\lambda_{01} + m_1(t)\lambda_{10} + m_3(t)\lambda_{30} + m_2(t)\lambda_{20} \\ \frac{dm_1(t)}{dt} = -m_1(t)\lambda_{10} - m_1(t)\lambda_{12} + m_0(t)\lambda_{01} \\ \frac{dm_2(t)}{dt} = -m_2(t)\lambda_{23} - m_2(t)\lambda_{20} + m_1(t)\lambda_{12} \\ \frac{dm_3(t)}{dt} = -m_3(t)\lambda_{30} - m_3(t)\lambda_{34} + m_2(t)\lambda_{23} + m_4(t)\lambda_{43} \\ \frac{dm_4(t)}{dt} = -m_4(t)\lambda_{43} + m_3(t)\lambda_{34} \end{cases} \quad (3)$$

where $m_i(t)$ is the average number of EDs in the i^{th} state at time t , λ_{ij} is the intensity of transition from the i^{th} state to the j^{th} state.

The normalizing condition for the new system of equations is defined by expression (4):

$$m_0(t) + m_1(t) + m_2(t) + m_3(t) + m_4(t) = N \quad (4)$$

where $m_i(t)$ is the average number of EDs in the i^{th} state at time t , N is the total number of EDs.

The method of dynamics of averages allows one to directly determine the mathematical expectation of the number of EDs in the EDMS that are in identical states. The more EDs and states an EDMS has, the more accurate the result of mathematical modeling becomes. The mass nature of the phenomenon makes the type of distribution not very essential.

The application of the method of dynamics of averages in modeling EDMS demonstrates high accuracy. This is due to the fact that in the limiting case, the summation and rarefaction of ED processing flows reduces to an elementary flow which is consistent with the property of continuous Markov processes.

V. EXPERIMENTS

Since a continuous Markov process is completely determined by the values of transition intensities, the following transition intensity matrix has been obtained for the specific ED type based on analysis of $N=1500$ EDs (Table 2).

TABLE II. TRANSITION INTENSITY MATRIX FOR THE MODEL PRESENTED IN FIG.1 (HOUR⁻¹)

	S ₀	S ₁	S ₂	S ₃	S ₄
S ₀	0	0.150	0	0	0
S ₁	0.030	0	0.040	0	0
S ₂	0.070	0	0	0.130	0
S ₃	0.060	0	0	0	0.005
S ₄	0	0	0	0.010	0

To find the limit values of the numbers of EDs in each state, a system of linear algebraic equations (SLAE) is formed (5):

$$\begin{cases} 0 = -m_0\lambda_{01} + m_1\lambda_{10} + m_3\lambda_{30} + m_2\lambda_{20} \\ 0 = -m_1\lambda_{10} - m_1\lambda_{12} + m_0\lambda_{01} \\ 0 = -m_2\lambda_{23} - m_2\lambda_{20} + m_1\lambda_{12} \\ 0 = -m_3\lambda_{30} - m_3\lambda_{34} + m_2\lambda_{23} + m_4\lambda_{43} \\ 0 = -m_4\lambda_{43} + m_3\lambda_{34} \end{cases} \quad (5)$$

where m_i is the limiting average number of EDs in the i^{th} state, λ_{ij} is the intensity of transition from the i^{th} state to the j^{th} state.

The solution of the SLAE represents the investigation of the stationary distribution in the EDMS: $m_0 = 302$, $m_1 = 647$, $m_2 = 129$, $m_3 = 281$, $m_4 = 140$.

With the given transition intensity matrix (Table 2), a large number of EDs are at the approval stage. Untimely transition of an ED to signing and execution stages may, in many cases, be critical and lead to significant losses for any organization, not just financial ones.

There is a need to distinguish between productive and non-productive states of EDs, assigning each one a multi-criteria evaluation C_i based on the benefits gained when an ED is in a productive state or the losses incurred when it is in a non-productive state. In general, this evaluation takes into account social, reputational, economic, organizational, and other factors, and can therefore be measured in conventional units [23].

In the context of the current experiment, signing (S_2) and executing (S_3) an ED are considered productive states, while drafting (S_0) and approving (S_1) an ED project are classified as non-productive states. The evaluations for each state in conventional units are as follows: $C_0 = 30$, $C_1 = 90$, $C_2 = 90$, $C_3 = 60$, $C_4 = 0$.

The task for the decision-maker (DM), using the decision-support system, is to manage the EDMS in a way that reduces the number of EDs in non-productive states while maximizing income from those in productive states. This is accomplished by optimizing the relationships among the average numbers of EDs in states and their corresponding transition intensities.

It is supposed that in the stationary operating mode of the EDMS, the DM knows/desires/requires constraints on the average numbers of EDs in states and transition intensities, determined by the quantity and qualifications of personnel, and the financial resources.

The task of optimizing the functioning of the EDMS can be formulated as follows (6):

$$F = C_2m_2 + C_3m_3 \rightarrow \max \quad (6)$$

with constraints (4), (5), (7):

$$\begin{aligned} m_0 &\leq 300 \\ m_1 &\leq 500 \end{aligned} \quad (7)$$

The optimality criterion (6) does not affect all states of the system, but only the productive ones. Thus, the multi-criteria optimization problem of the EDMS functioning is presented as a single-criterion problem by convolution of criteria for each optimized state into one.

Relations (4) and (5) are normalizing and define the initial conditions for solving the SLAE, as well as the total number of EDs in the system over the modeled time interval. The constraints (7) on the average numbers of EDs in states are designed to reduce the number of EDs in non-productive states.

Optimization is performed not only on the average numbers of EDs in states, but also on certain transition intensities, which within the framework of the problem under consideration are control parameters. The list of such parameters is determined by the DM based on their experience, intuition, knowledge and understanding of the organization's business processes.

VI. RESULTS

The optimization results are presented in tables (Table 3, Table 4, Table 5).

TABLE III. OPTIMIZATION RESULTS FOR TRANSITION INTENSITIES SELECTED AS CONTROL PARAMETERS

Control parameter	As is (hour ⁻¹)	As to be (hour ⁻¹)
λ_{01}	0.15	0.25
λ_{10}	0.03	0.06
λ_{12}	0.04	0.06
λ_{20}	0.07	0

TABLE IV. OPTIMIZATION RESULTS FOR AVERAGE NUMBERS OF EDs

Control parameter	As is (ED)	As to be (ED)
m_0	302	208
m_1	647	424
m_2	130	205
m_3	281	442
m_4	140	221

TABLE V. OPTIMIZATION RESULTS FOR THE OBJECTIVE FUNCTION

Strategy	Objective function (conventional units)
Before optimization	28560
After optimization	44970

Based on the analysis of decision-making consequences in the organization, it is proposed to consider control optimization parameters as numerical security indicators of the EDMS in terms of availability. These values help determine the effectiveness of active measures protecting EDs from information security threats and establish requirements for ED processing time.

The optimization analysis reveals the need for organizational protection measures to prevent comments on ED drafts during senior management approval, particularly during the signature process. The organization needs to implement measures to reduce both the regulated preparation time for ED drafts and the time spent incorporating reviewers' comments.

The increased transition intensity from the approval stage (S_7) to the preparation stage (S_0) is justified by the principle that issues should be identified and resolved in early routing stages rather than at the end of the process.

VII. CONCLUSIONS

The model of the dynamics of averages of Markov random process theory is developed, which takes into account all the existing shortcomings of the solutions considered and allows for modeling the state of EDs, evaluating the effectiveness of implemented protective measures of EDMS operation.

In terms of ensuring availability, this model allows for assessing the workload of various services, identifying bottlenecks, and reducing the risks of failing to meet set production tasks due to a significant number of excessive approval iterations.

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Mathematical Model for Information Security Risk Assessment in Electronic Document Management Systems

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Abstract—The transition to electronic document management systems (EDMS) has evolved into a mission-critical digital transformation initiative. Ineffective implementation of EDMS and its associated business processes can result in operational disruptions, financial losses, missed deadlines, and reputational damage. This situation necessitates the integration of manageable information flows within business processes into the sphere of information security management procedures. A structured approach is proposed to analyze existing business processes with attention to conducting quantitative risk assessment through modeling. Analysis is performed within the developed decision support system to optimize business processes in the EDMS while considering both system quality and information security requirements.

Keywords—Markov process, electronic document, electronic document flow system, security metric, risk, availability

I. INTRODUCTION

Private and public sector organizations are actively implementing digital transformation initiatives, including the adoption of electronic document management systems (EDMS). The requirements for system reliability and information security (IS) continue to increase, driven by emerging information security threats (IST) and the growing complexity of selecting appropriate protective measures for EDMS [1, 2].

Business process owners systematically assess the criticality of reliable information circulating within the EDMS. Imperfections in the organization of manageable information flow (MIF) processes, expressed in any possible deviations from established organizational regulations for

electronic document (ED) processing and capable of leading to information blocking, may create serious threats to the organization's assets. Such threats are connected with the strategic value of business information processing, the reaction of involved parties (counterparties), and the organization's reputation. Damage from the implementation of threats to the availability of information processed in EDMS is expressed in actual violation of the specified level of IS (loss of availability), disruption of the organization's operational activities, financial losses, violation of plans and deadlines, and deterioration of the organization's reputation. This necessitates the integration of MIF business processes into the sphere of IS management procedures (ISO/IEC 27005:2022).

There are methodologies proposed by national and foreign authors that allow for general IS assessment in various types of EDMS, but without proper attention to risks and without implementing any visualization methods or operational analysis of results [3-18].

II. PROBLEM STATEMENT

Deviations in ED routing can prevent timely delivery to intended recipients (Fig. 1). This creates an access blockage for specific EDMS users along the processing route, effectively disrupting legitimate users' access to information. Such disruptions compromise information availability within the EDMS – a key IS property that ensures authorized subjects can access objects when needed. These considerations drive the fundamental IS and reliability requirements for EDMS implementation.

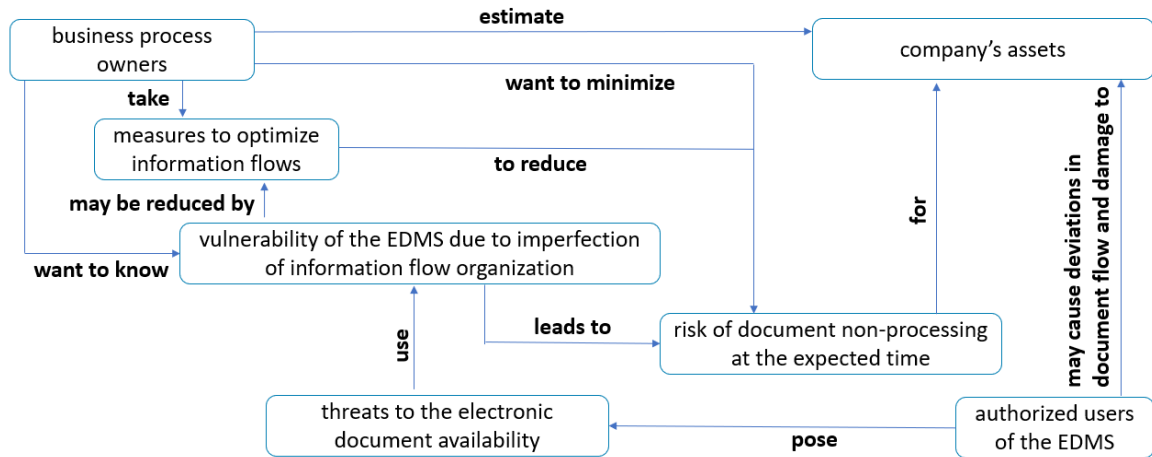


Fig. 1. Conceptual model of IS for EDMS considering availability threats.

Business process owners implement strategic measures to optimize MIF processes in EDMS in order to minimize EDMS vulnerabilities related to the availability of processed information. Special attention is paid to monitoring the actions of authorized users, as they tend to unintentionally or deliberately deviate from established regulations, causing failures in ED circulation.

III. METHODS

A. Scheme of Markov Process

Within standard operational workflows, EDs progress through a defined lifecycle consisting of draft preparation, approval stages, formal signing, execution processes, and archiving. EDs are considered to shift instantaneously between defined states, with no time allocated for the transition process itself.

EDMS business operations function as state-transition processes driven by event flows. These operations are effectively represented through discrete Markov random processes with continuous time, where transition intensities vary inversely with the average processing duration for each ED classification.

For specific ED type following established processing route, a detailed EDMS model has been developed with the following distinct states: S_0 - ED approval by the deputy director for contract activity and pricing, S_1 - ED approval by the deputy director for economics and finance, S_2 - ED approval by managing director, S_3 - ED approval by the procurement department, S_4 - ED approval by the legal department, S_5 - ED archiving, S_6 - approval of budget, S_7 - ED execution, S_8 - ED draft preparation, S_9 - ED consideration and signing.

The dynamic behavior of the EDMS, characterized by both directional transitions and varying event flow intensities, is mathematically represented through a system of Chapman-Kolmogorov differential equations that define state probabilities (1):

$$\frac{dp_i(t)}{dt} = -p_i(t) \sum_{j \neq i}^n \lambda_{ij}(t) + \sum_{i \neq j}^n \lambda_{ji}(t) p_j(t) \quad (1)$$

where $p_i(t)$ is the probability function of the i^{th} state, $\lambda_{ij}(t)$ is the transition intensity function from the i^{th} state to the j^{th} state, $(n+1)$ is the number of states.

Solving the system of differential equations is solving the well-known Cauchy problem. Determining the probabilities of each state $p_i(t)$ at any moment in time t can serve as an assessment of system efficiency.

B. Method of Dynamics of Averages

For EDMS handling large volumes of EDs, a more efficient mathematical approach — the method of dynamics of averages — can be applied to model system behavior. In this regard, the operational characteristics of EDMS are defined by the system dynamics of homogeneous ED types which follow common patterns in how they are routed, processed, and transition between different states of ED lifecycle.

The system dynamics is described by a system of differential equations in terms of the average number of EDs in each state (2):

$$\frac{dm_i(t)}{dt} = -m_i(t) \sum_{j \neq i}^n \lambda_{ij}(t) + \sum_{i \neq j}^n \lambda_{ji}(t) m_j(t) \quad (2)$$

where $m_i(t)$ is the function of the average number of EDs in the i^{th} state, $\lambda_{ij}(t)$ is the transition intensity function from the i^{th} state to the j^{th} state, $(n+1)$ is the number of states.

The dynamics of averages method provides a mathematical framework for calculating the expected number of EDs that occupy identical states within an EDMS.

Investigation of the stationary distribution of the EDMS is found from a system of linear homogeneous algebraic equations (3):

$$m_i \sum_{j=0}^n \lambda_{ij} = \sum_{j=0}^n \lambda_{ji} m_j, \quad (3)$$

where m_i is the limit value of the average number of EDs in the i^{th} state, λ_{ij} is the intensity of transition from the i^{th} state to the j^{th} state, $(n+1)$ is the number of states.

The dynamics of averages method proves highly accurate for EDMS modeling because, in the limiting case, the aggregation and dispersion of ED processing flows converge to an elementary flow, aligning with the elementary flow property of continuous Markov processes [19].

C. Variance-Based Risk Assessment Approach

The EDM model based on the scheme of Markov processes allows for a transition to numerical assessment of IS risks in EDMS, which corresponds to the known approach of ISO series 31000 and 27005.

Based on the developed EDM functioning model, in a broad sense risk is defined as the standard deviation of system parameters (specifically, the average numbers of ED states) from their expected values, following a variance-based risk assessment approach (4):

$$\sigma_j(t) = \sqrt{m_j(t) \left(1 - \frac{m_j(t)}{N} \right)} \quad (4)$$

where $m_j(t)$ is the function of the average number of EDs in the j^{th} state, $\sigma_j(t)$ is the standard deviation of the average number of EDs in the j^{th} state, N is the total number of EDs.

In the context of risk assessment for EDMS, EDs can exist in either productive or non-productive states. Each of these states is associated with a multi-criteria assessment value, denoted as C_i . For productive states, this value represents the benefits that functioning EDs bring to the system, while for non-productive states, it represents the associated losses. In general, C_i is determined taking into account social, reputational, economic, organizational and other aspects, therefore C_i can be evaluated in conventional units [20].

The variance-based model of risk assessment proposed in this research allows one to identify risk of under-receiving benefits from productive states of EDs and total risk of losses associated with non-productive states of EDs. These risks are determined by taking into account various combinations of m_j and λ_{ij} which serve as control parameters for optimization.

D. Multi-Criteria Optimization Problem Formulation

A multi-criteria optimization problem can be formalized. The following optimization criteria have been identified:

- maximization of income from EDs in productive states (5),
- minimization of the sum of risks of losses from non-productive states of EDs (6),
- minimization of the risk of under-receiving income from EDs in productive states (7),
- the weighting formula «income – risk» (8), (9),

$$F_1 = \sum_i C_i m_i \rightarrow \max \quad (5)$$

$$F_2 = \sum_j C_j \sqrt{D_j} \rightarrow \min \quad (6)$$

$$F_3 = \sum_i C_i \sqrt{D_i} \rightarrow \min \quad (7)$$

$$F_4 = F_1 - F_2 \rightarrow \max \quad (8)$$

$$F_5 = F_1 - F_3 \rightarrow \max \quad (9)$$

where C_j represents the losses attributed to EDs of a functioning EDMS in the j^{th} non-productive state, C_i represents the benefits provided by EDs of a functioning EDMS in the i^{th} productive state, D_i is the variance of the average number of EDs in the i^{th} productive state, D_j is the variance of the average number of EDs in the j^{th} non-productive state, m_i is the average number of EDs in the i^{th} productive state.

The optimization problem can be solved through various combinations of average numbers of EDs in each state and their corresponding intensities, where some parameters are fixed while others are variables to be optimized. These combinations represent different EDMS operation strategies which are defined by the decision maker (DM).

While DM can consider multiple strategies, the process requires automated computational support. Therefore, system modelling, strategy generation, optimization problem solving, and results presentation are implemented through a developed by the author Decision Support System (DSS) [21].

IV. EXPERIMENTS

For the specific EDMS model, based on statistical data for $N=1528$ EDs, a matrix of transition intensities has been determined (Table 1).

TABLE I. TRANSITION INTENSITY MATRIX FOR THE SPECIFIC ED TYPE (HOUR⁻¹)

	S ₀	S ₁	S ₂	S ₃	S ₄	S ₅	S ₆	S ₇	S ₈	S ₉
S ₀	0	0,09	0,10	0	0,08	0	0	0	0	0
S ₁	0	0	0	0	0,06	0	0	0	0,04	0
S ₂	0	0	0	0	0	0	0	0	0,05	0,15
S ₃	0,20	0	0	0	0	0	0	0	0	0
S ₄	0	0	0,07	0	0	0	0	0	0,09	0,07
S ₅	0	0	0	0	0	0	0	0,01	0	0
S ₆	0,14	0,09	0	0,08	0	0	0	0	0,11	0
S ₇	0	0	0	0	0	0,002	0	0	0,11	0
S ₈	0,07	0,03	0,04	0	0,03	0	0,13	0	0	0
S ₉	0	0	0	0	0	0	0	0,13	0,09	0

In the stationary distribution the specific EDMS model has the following characteristics of average numbers of EDs in states: $m_0 = 138$, $m_1 = 288$, $m_2 = 178$, $m_3 = 35$, $m_4 = 153$, $m_5 = 39$, $m_6 = 80$, $m_7 = 197$, $m_8 = 253$, $m_9 = 167$.

The transition intensity matrix shows that EDs are frequently stuck in approval stages. Analysis reveals a major inefficiency where 19% of EDs remain pending with the deputy director for economics and finance, while only 13% are actually being executed. This situation requires both a risk assessment of current EDMS operations and new management strategies for managing EDMS in terms of IS criteria and efficiency.

The costs of states in conventional units are defined as follows: $C_0 = 12$, $C_1 = 30$, $C_2 = 15$, $C_3 = 25$, $C_4 = 9$, $C_5 = 0$, $C_6 = 21$, $C_7 = 60$, $C_8 = 30$, $C_9 = 7$.

Several management strategies are to be considered:

- strategy 1 involves fixing S_2 , S_5 , S_9 ;
- strategy 2 involves fixing S_0 , S_5 , S_6 ;

- strategy 3 involves fixing S_3 , S_4 , S_5 , S_6 ;
- strategy 4 involves fixing S_2 , S_4 , S_5 .

V. RESULTS

Table 2 summarizes the optimal criteria values across different strategies. The analysis uses ED processing times at each stage as IS indicators for EDMS optimization.

TABLE II. OPTIMAL VALUES OF CRITERIA BY STRATEGIES (CONVENTIONAL UNITS)

Strategy	F ₁	F ₂	F ₃	F ₄	F ₅
Before optimization	11820	1737	786	10083	11034
Strategy 1	13789	1542	762	12247	12951
Strategy 2	23400	1220	762	22153	22377
Strategy 3	23234	1292	762	21762	22214
Strategy 4	21794	1190	762	20412	20795

Strategy 2, identified as the optimal compromise solution, requires specific operational changes: reducing legal department review time to 8 hours (60% faster than operations before optimization), and establishing a 9-hour limit for senior management ED processing.

Implementation of these measures will potentially lead to a 98% increase in the integral income indicator, a 30% reduction in the risks of losses from non-productive states of ED, and a 3% reduction in the risk of income shortfall. It should be noted that the optimization target functions are complex in nature and combine organizational, financial, reputational and other aspects. The analysis provides DM with model-driven recommendations for identifying and addressing EDMS bottlenecks.

VI. CONCLUSIONS

The system of interrelated mathematical models has been developed for EDMS optimization. This system combines Markov random process theory with variance-based risk assessment and multi-criteria decision making. This integrated approach enables identification of system vulnerabilities and quantitative assessment of IST. The model system specifically addresses ED processing issues such as approval delays and route deviations, while providing measurable security metrics. It supports optimization of MIF by incorporating both security criteria and operational efficiency measures.

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Development of a Fiber-Optic Angular Displacement Recorder

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Abstract— The article discusses the problem of constructing a mathematical model of a fiber-optic recorder designed to measure the angles of inclination of a reflecting surface. The model is based on geometrical relations between the transmitting and receiving fibers and takes into account the surface rotation angle, beam output coordinates and conditions of signal registration by the photodetector. A numerical simulation of the dependence of the output signal on the distance between the fiber end and the reflecting surface at a fixed tilt angle, as well as on the tilt angle at a fixed distance has been carried out. The modeling results are compared with the experimental data, and the discrepancy does not exceed 7.1%. A calibration method is proposed to ensure the reproducibility of the transfer characteristic when the reflective properties of the surface change. The design of the measuring device was developed, the signal conversion scheme was realized and experimental measurements were carried out, which confirmed the possibility of registering angles in the range of $\pm 7^\circ$ with an error of no more than 1.5%.

Keywords— *fiber-optic recorder, angular displacements, mathematical modeling, sensitivity*

I. INTRODUCTION

The task of measuring small tilt angles is important for the assembly and adjustment of equipment in mechanical engineering, tilt angles in the automotive industry, control and positioning of elements in construction. With the high requirements for accuracy and stability of measurements, non-contact measurement methods, in particular fiber-optic technologies, are becoming increasingly relevant. Fig. 1 shows the growing trend in the filing of patents for this type of measuring device. As can be seen from the graph, in recent years, interest in the development of these devices has increased several times compared to previous decades. According to Google Patents, a search for the name “Fiber-optic Angular Displacement sensor” reveals more than a hundred thousand patents for this type of devices [1], of which the largest number relates to the engineering field.

Fiber-optic vibration sensor (FOVS) [4] is connected to a personal computer (PC) via a serial port, which entails a number of restrictions in terms of the dissemination of measured information.

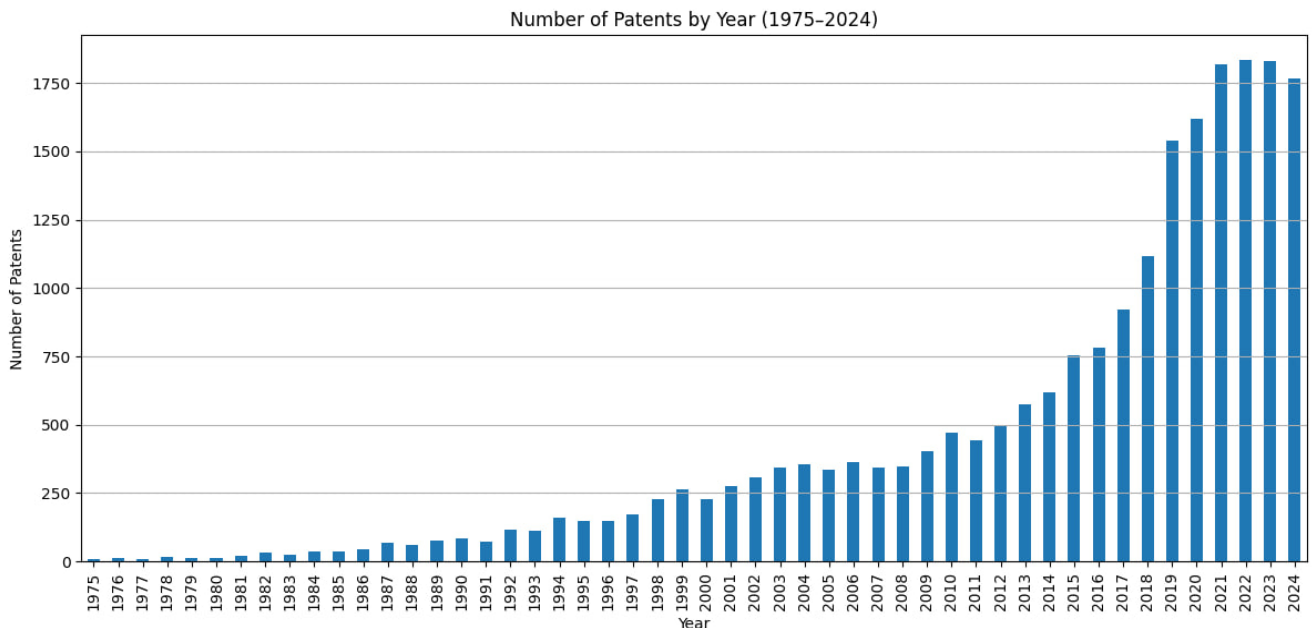


Fig. 1. Patent filing trend from 1975 to 2024.

First of all, the range of use of the sensor is limited by the length of the wire. For production, this means that a large number of cables must be laid. Moreover, the possible number of connected FOVS does not exceed the number of USB interfaces of a particular PC. When connecting new sensors, additional cables are required, which can be difficult in limited space or in existing infrastructures.

Fiber-optic sensors are based on optical properties of fiber materials and provide a wide range of possibilities for measuring various physical quantities [2]. Due to their high sensitivity and resistance to aggressive environmental conditions, fiber-optic sensors are often used in various technological and scientific tasks, where traditional measurement tools lose their effectiveness. Such conditions include elevated temperature, strong electromagnetic fields [3], chemically active environments and radiation-hazardous areas. A key advantage of fiber-optic sensors is their ability to accurately and reliably measure parameters in situations where the use of electrical transducers is impossible or high risk. These devices make it possible to measure pressure, displacement, temperature, liquid level and other parameters in conditions beyond the limits of acceptable norms for classical sensors [4].

Fiber-optic sensors demonstrate versatility and a wide range of applications in various industries: medicine [5], telecommunications, industry [6], robotics [7], structural monitoring and environmental sensing.

To investigate the characteristic of a fiber-optic sensor at angular displacements of the reflecting surface, it is most appropriate to build a sensor model, check its adequacy and, if the verification result is positive, evaluate the sensor characteristics on the model.

The most technologically advanced fiber-optic sensors are of the reflectometric type, in which the measurement information is obtained by reflection from the object surface. It is reasonable to develop a model of the angular displacement sensor for a sensor of this design.

II. BUILDING A MATHEMATICAL MODEL OF THE ANGULAR DISPLACEMENT RECORDER

To simplify the calculations, an idealized model of the fiber-optic recorder is used in this paper, in which assumptions are introduced that significantly reduce the computational complexity without significant loss of accuracy. In particular, the LED is considered as a point source of radiation, and the exit angle from the optical fiber is equal to the entrance angle. Due to the nature of mode propagation in the fiber structure, the assumption of random location of ray exit points along the end of the transmitting fiber was made. The scheme of obtaining measurement information is shown in Fig. 2 where S_1 is the diameter of the transmitting S_2 is the receiving fiber, d is the distance between them, h is the distance from the transmitting fiber to the rotary axis, α is the angle of beam exit from the LED, β - angle of rotation of the reflecting surface and γ - angle of incidence on the receiving fiber, AB - distance from the left edge of the transmitting fiber to the point of beam exit from the fiber, L - distance from the beginning of the end face of the transmitting fiber to the point of intersection of the reflected beam with the plane of the fiber end face.

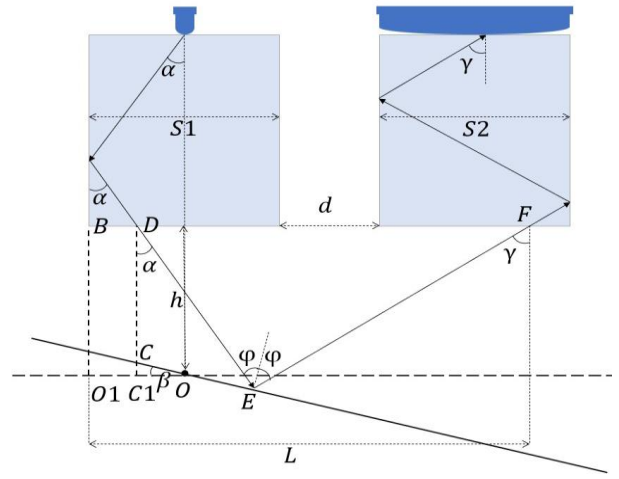


Fig. 2. Scheme for obtaining measurement information

L is calculated by the formula (1), derived from the analysis of geometric dependencies:

$$\varphi = \pi/2 - (\pi - \alpha - (\pi - (\pi/2 - \beta))) = \alpha + \beta$$

$$\gamma = \pi/2 - (\pi - (\pi/2 - \alpha) - 2\varphi) = \alpha + 2\beta$$

$$OC_1 = \frac{S_1}{2} - AB$$

$$CC_1 = OC_1 \tan \beta$$

$$BC = h - CC_1$$

$$BE = \frac{BC}{\sin(\frac{\pi}{2} - \varphi)} \sin(\frac{\pi}{2} + \beta) = \frac{h - (\frac{S_1}{2} - AB) \tan \beta}{\cos \varphi} \cos \beta$$

$$\frac{BF}{\sin 2\varphi} = \frac{BE}{\sin(\frac{\pi}{2} - \gamma)} \Rightarrow$$

$$BF = \frac{BE \cdot \sin 2\varphi}{\sin(\frac{\pi}{2} - \gamma)} = \frac{BE \cdot \sin 2\varphi}{\cos \gamma} = \frac{2 \sin(\alpha + \beta)}{\cos(\alpha + 2\beta)} * (h \cos \beta - (\frac{S_1}{2} - AB) \sin \beta)$$

$$L = AB + \frac{2 \sin(\alpha + \beta)}{\cos(\alpha + 2\beta)} * (h \cos \beta - (\frac{S_1}{2} - AB) \sin \beta) \quad (1)$$

The criterion of the beam hitting the receiving fiber is the fulfillment of the condition:

$$S_1 + d \leq L \leq S_1 + d + S_2$$

Hitting these limits means registration of the corresponding signal by the photodetector. For quantitative estimation of the model output signal, the contribution of all admissible beams that have passed the way from the transmitting fiber, reflected from the surface and hit the receiving fiber is summed up, taking into account the sensitivity of the photodiode and the intensity of LED radiation at the corners. For convenience of analysis of the modeled dependencies, the values are normalized.

To check the adequacy of the model, the dependence of the output voltage on the distance h between the end of the transmitting fiber and the reflecting surface for diameters $S_1 = S_2 = 2$ mm was simulated. The same dependence was obtained experimentally and normalized. The comparison of experimental and modeled values is shown in Fig. 3.

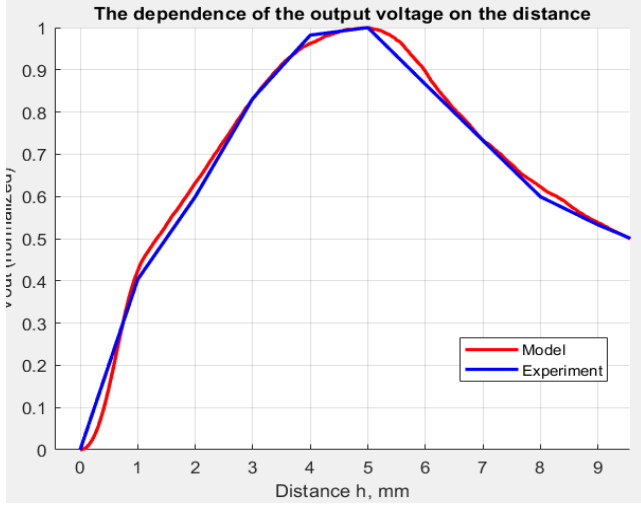


Fig. 3. Voltage dependence on the distance between the reflecting surface and the plane of the fiber end face

The modeling results show that the maximum value of the photodetector signal is achieved at a distance $h = 5$ mm between the end of the transmitting fiber and the reflecting surface. Insignificant discrepancies (less than 7.11%) between the experimental data (blue curve) and the results of numerical simulation (red curve) are explained by a relatively large sampling step chosen during measurements (1 mm), as well as by a number of assumptions adopted in the construction of the mathematical model. Due to the nature of the detected deviations and their influence on the shape of the output signal, the realized model may be considered adequate.

III. ANALYSIS OF SIGNAL AND SENSITIVITY DEPENDENCE ON THE DISTANCE TO THE REFLECTING SURFACE AND ANGULAR DISPLACEMENTS

A simplified method based on linear approximation is used to quantify the sensitivity of the device at different distances. The sensitivity at a given distance is defined as the slope of a straight line plotted by two values of the output signal obtained at symmetrical angles of inclination of the reflecting surface $\pm 10^\circ$. This approach provides a reduction in computational complexity while maintaining informativeness.

To clearly demonstrate the method, plots of maximum output signal and sensitivity versus distance for fibers of different diameters in the range from 1 to 5 mm with a step of 0.5 mm were plotted and shown in Fig. 4. In addition, three key parameters were determined for each diameter: the distance at which the maximum output signal is reached, the distance corresponding to the maximum sensitivity, and their ratio.

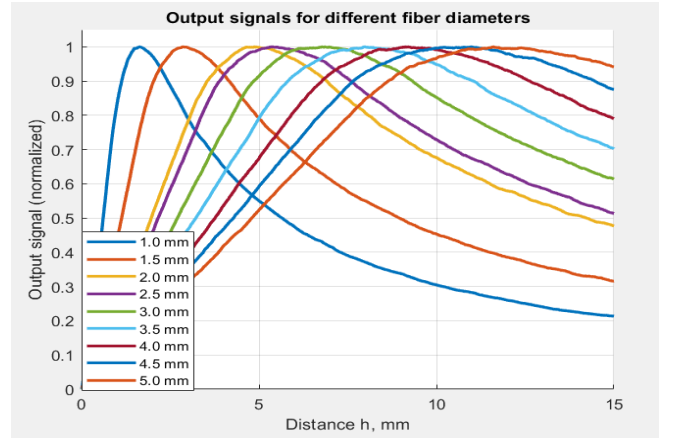


Fig. 4. Dependence of the output signal on the distance between the reflecting surface and the plane of the fiber end for different fiber diameters

It was found that although the absolute values of the output signal and sensitivity depend on the fiber diameter, the ratio k of the distance at which the maximum signal is achieved (h_{msig}) to the distance at which the maximum sensitivity is achieved (h_{msen}) remains practically constant and is 0.6 ± 0.03 .

The Fig. 5 shows the dependences of the output voltage at changing the angle of inclination of the reflecting surface, obtained by modeling (solid curves) and experimentally (curves are made by dashed line). The divergence of the curves is no more than 3.03%. Thus, it may be concluded that the sensor of the proposed design can measure the angular displacements of the reflecting surface. Since the angle of inclination of the reflecting surface can have any sign, and the obtained transfer characteristic is asymmetric, it is advisable to introduce a second receiving channel into the sensor design, as shown in the Fig. 6.

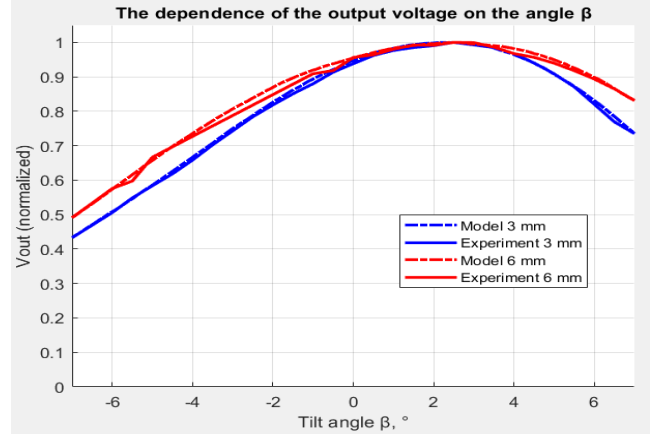


Fig. 5. Dependence of the sensor output voltage on the angle of inclination of the reflective surface

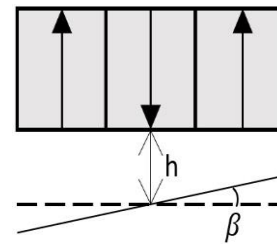


Fig. 6. Schematic diagram of a two-channel sensor for measuring surface inclination angles

The output signal level of the sensor channels is affected by the position of the fiber end relative to the reflective

surface, the surface reflectance coefficient, the angle of inclination, and the power of the light flux emitted by the LED. Errors caused by these factors can be compensated for by performing calibration before starting measurements. The essence of calibration is to control the light flux of the LED to achieve a fixed response value at the maximum point for any reflective surface. During calibration, the sensor is placed at a distance from the reflective surface that is guaranteed to be greater than the maximum point. It is necessary to ensure that the end of the light guide is at a right angle to the reflective surface, i.e., the signals of the receiving channels differ by no more than 5%. Next, by reducing the distance between the reflective surface and the end of the light guide, you should pass the maximum point, at which the light flux intensity adjustment procedure will be performed so that the output signal is equal to a certain value (in this case, 2.5 V). The effective distance between the end of the light guide and the reflective surface is the distance at which the output signal is approximately 60% of the signal at the maximum point. To evaluate the adequacy of the algorithm, the mirror-like metal surface and the surface with a roughness class of 4 were calibrated, after which the

angular displacements were measured. The measurement results for both surfaces in both channels of the measuring device are shown in the Fig. 7. As can be seen from the Fig. 7, the discrepancy in characteristics when reflecting from surfaces with different surface finish purity does not exceed 1.47%.

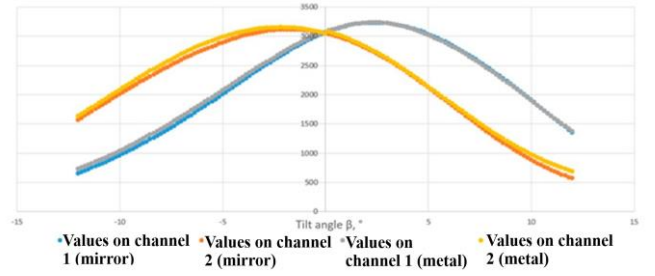


Fig. 7. Transmission characteristics when reflecting from materials with different surface finish purity after calibration

Based on the above, a structural diagram of the angular displacement recorder has been developed, as shown in the Fig. 8.

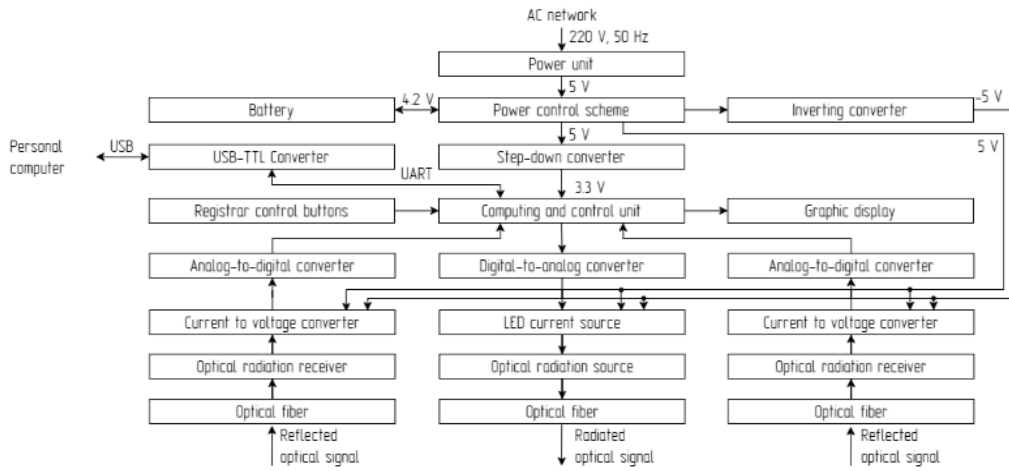


Fig. 8. Block diagram of the angular displacement recorder

The recorder is powered by a 220 V AC mains supply via a switching power supply unit. The stabilized 5 V voltage is supplied to the power control circuit, which controls the battery charge, as well as to the recorder's inverting converter, which generates a -5 V voltage to power the analog nodes, and a 3.3 V step-down converter to power the microcontroller of the computing and control unit. The computing and control unit generates the LED current, processes incoming signals, and interacts with external devices. A USB-TTL converter is provided for communication with a PC. Control buttons are provided to control the operating modes, and a graphic display is used to display information. In measurement mode, the control voltage generated by the microcontroller's built-in DAC is fed to the LED current control circuit. The LED's light flux passes through the transmitting light guide to the reflective surface. The reflected light enters the receiving optical fibers, at the outputs of which the radiation is registered by photodetectors that convert it into current. Then, the photocurrent is fed to the current-to-voltage conversion circuits, which ensure that the signal level corresponds to the input range of the ADC. After conversion to digital form, the obtained values are transmitted to the computing and control unit, where subsequent data processing and indication of results are carried out, as well as, if necessary, transmission via the UART interface to a personal computer. The power

supply for the current source circuits and current-to-voltage converters is ± 5 V.

IV. CONCLUSIONS

Based on the structural diagram shown, an electrical schematic diagram of the recorder was developed, built-in microcontroller software was developed, a prototype of the recorder was manufactured and debugged, and evaluation tests were conducted. The test results are shown in the 0.

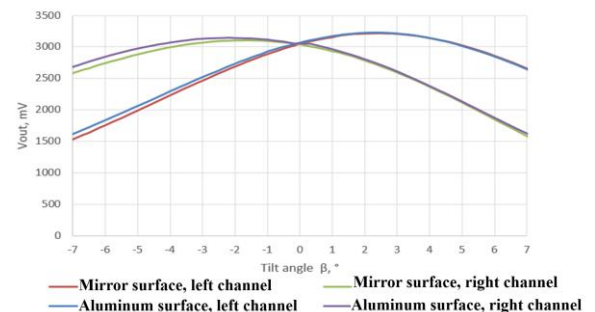


Fig. 9. Conversion functions of the angular displacement recorder channels when reflecting from different surfaces Analysis of the results showed that the measurement range of the model is $\pm 7^\circ$, and the maximum relative measurement error does not exceed 1%.

Further research will focus on expanding the range of measurable angular displacements, increasing the structural sensitivity of the sensor, and developing a digital twin of the fiber-optic sensor.

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Section 2 - Digital Security

- **Technological, Technogenic, Information and Communication, and Transport Security and Safety**
- **Financial Security Systems**

Unconditionally Secure Transform for High-Order Markov Sources via Splitting

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Abstract—We consider the problem of unconditionally secure encryption of messages generated by Markov sources. Unconditional security is achieved by grouping messages into equal probability sets and their enumeration within a particular set, so that even the exhaustive key search in decryption by the adversary will produce the equally probable messages whose number is determined only by the number of possible keys (giving the adversary no means to select the right message). While the known enumeration schemes have the per-symbol complexity exponential in the order of the source, the suggested transform has polynomial complexity, being easily applicable to the “high order” Markov sources. This is done by getting rid of enumeration of the whole set of equally probable messages but working with the subsets obtained by splitting the Markov source into a number of memoryless sources. Then the source message is transformed into another message with the use of the secret key.

Keywords—unconditional security, ideal cipher, Markov source, enumeration, source splitting.

I. INTRODUCTION

Modern secret-key ciphers used to protect data by encryption can be partitioned into two main classes: computationally secure and unconditionally secure schemes. Computational security means that there are no efficient algorithms to break a cipher whereas the exhaustive key search (an inefficient algorithm of exponential complexity) can always break it. Computationally secure ciphers such as AES, ChaCha, etc, are commonly used in practice. The main trouble with them is the absence of strict proofs for non-existence of efficient breaking algorithms. Some people from security agencies claim that they have heard of 7 secret theorems on breaking such ciphers. In contrast, unconditional security means that a cipher cannot be broken in principle by any (even exponentially complex) algorithm. The well-known example of unbreakable cipher is the one-time pad (also called the Vernam cipher). Shannon [1] proves, using information-theoretic arguments, that this cipher cannot be broken provided the length of the key equals the length of the message, the key is completely random, and used only once. Under these conditions, the ciphertext carries no information about the plaintext, so the one-time pad, according to Shannon, is a perfect cipher. The obvious drawback of one-time pad is the necessity to maintain long one-time secret keys. Another alternative considered by Shannon is a so-called (strongly) ideal cipher. This cipher can operate with short long-term keys as far as decryption with any key results in a message of an equal probability set of the same source. Here the number of equally probable decryptions is equal to the number of possible keys, which gives little chance to the adversary to find the right message.

Further developments in the field, after the seminal Shannon work of 1949, had appeared sporadically. In 1998, in a number of works, homophonic coding was suggested to facilitate the construction of ideal ciphers for sources with known statistics [2–4]. In 2000, Ryabko [5] was the first to show how to efficiently encode a message in order to build an ideal cipher in case the source statistics were unknown, the construction being based on enumerative coding. Then a similar construction based on homophonic coding was suggested in [6]. A distinctive feature of these methods was to represent a code in two distinct parts with the second part indistinguishable from a completely random sequence. Then only the second part was encrypted, while the first part (in a sense, the description of the source model) remained open. However, the suggested methods were quite inefficient in practice when applying to Markov sources (where the probability of the current symbol depends on a number of preceding symbols) since they required to transmit a huge model description before the encrypted code.

Meanwhile, in 2002, Russell and Wang [7] and then Dodis and Smith [8] proposed a new approach called “entropic security”. They show that if a source has sufficient min-entropy (determined by the most probable message) then it is possible to construct an unbreakable cipher with a much shorter key than the message length. The adversary will have non-zero but negligibly small probability to recover the encrypted message. In 2014, Juels and Ristenpart [9] suggested a “honey encryption” which by means of special coding ensured a plenty of likely decryptions for the adversary, a property close to Shannon ideal ciphers. An attempt to combine honey encryption and entropic security was made in [10]. In 2023, Ryabko [11] applied the methods from ideal cipher domain within the framework of entropic security which resulted in essential reduction in the key length: in case of known statistics the length of the key is constant, and in case of unknown statistics it grows with logarithmic rate with respect to the message length. The suggested approach depends essentially on efficient enumeration of Markov sources.

We draw our attention to constructing ideal ciphers for messages generated by Markov sources. We improve over the previously known methods in two aspects. First, we suggest to change the paradigm of coding-then-encrypt to encrypted transforms of source messages. This allows to get rid of huge model description as a part of code which is especially important for high-order Markov sources. The message is transformed into another message of the same probability class (without increasing its length). It can be further compressed by standard methods. So we obtain a compact representation rather than an impractically large code sequence. Second, we greatly reduce the complexity of enumeration and denumeration (which is an essential part of

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known methods for ideal ciphers) by working not with the whole set of equally probable messages but with some subset containing the message to be encrypted.

II. MEMORYLESS CASE

We first describe the suggested technique for memoryless sources and then generalize it for Markov sources. Consider a stationary memoryless source generating letters over the alphabet $A = \{a_1, a_2, \dots, a_N\}$ with unknown probabilities. Let the source message be $X = x_1 x_2 \dots x_n$, each $x_i \in A$. Denote by n_i , $i = 1, 2, \dots, N$, the number (quantity) of letters a_i in X . Obviously, the value of each n_i lies in the range from 0 to N , and $\sum_{i=1}^N n_i = n$. Since the letters in X are statistically independent, any combination containing the same number of individual letters is equally likely. Denote the set of all such combinations (or a class to whom message X belongs) by $C(X) = C(n_1, n_2, \dots, n_N)$ and assume that the members of $C(X)$ are ordered lexicographically so that any combination has a unique ordinal number $\nu(X)$ starting from 0. The total number of different combinations can be computed as

$$S = \frac{n!}{n_1! n_2! \dots n_N!}$$

These observations give us a way to determine the so-called faithful probabilities given the set of counters n_i . Denote by S_j the number of combinations in the rest of the message $x_j x_{j+1} \dots x_n$ and by $S_j(i)$ their share where $x_j = a_i$ (so $S = S_1$). Then for the first symbol of the message we have the following distribution:

$$P(x_1 = a_i) = \frac{S_1(i)}{S_1} = \frac{n_i}{n}. \quad (1)$$

When we observe the first symbol, let it be a_k , we decrement by 1 the counter n_k . Then for the second symbol (with new value of n_k)

$$P(x_2 = a_i) = \frac{S_2(i)}{S_2} = \frac{n_i}{n-1}. \quad (2)$$

And so on to the last symbol.

Consider an example. Let $A = \{a, b, c\}$, $N=3$ and the message $X = acaba$, $n = 5$, $n_a = 3$, $n_b = 1$, $n_c = 1$. $C(X)$ and $\nu(X)$ are

0: aaabc	5: aacba	10: acaba	15: bcaaa
1: aaacb	6: abaac	11: acbaa	16: caaab
2: aabac	7: abaca	12: baaac	17: caaba
3: aabca	8: abcaa	13: baaca	18: cabaa
4: aacab	9: acaab	14: bacaa	19: cbaaa

Let us find the faithful probability distributions for all message symbols according to (1), (2), etc:

	a	c	a	b	a
$p(a)$	3/5	2/4	2/3	1/2	1
$p(b)$	1/5	1/4	1/3	1/2	0
$p(c)$	1/5	1/4	0	0	0

Faithful probabilities allow us to compute an ordinal number $\nu(X)$ in $C(X)$ with the use of block version of Gilbert–Moore alphabetic coding [12]. Define cumulative probabilities q as follows. Let $q(a_1) = 0$, then $q(a_k) = q(a_{k-1}) + p(a_{k-1})$, $k = 2, \dots, N$ (in other words, cumulative probability is the sum of probabilities of preceding letters in the alphabet). To continue our example,

	a	c	a	b	a
$q(a)$	0	0	0	0	0
$q(b)$	3/5	2/4	2/3	1/2	1
$q(c)$	4/5	3/4	2/3	1/2	1

Each letter u can be represented by the interval $[q(u), q(u) + p(u))$ within the unit interval $[0, 1)$. Similarly, every message $X \in C(X)$ can be represented by its interval and the beginning of that interval is the ordinal number $\nu(X)$. Denote by L the left bound of the interval and by R the width of the interval (range). To compute the interval for the message one can use the following iterative algorithm:

```

L ← 0, R ← 1.
FOR j = 1, 2, ..., n DO
    L ← L + R q(x_j),
    R ← R p(x_j).

```

After the completion of the algorithm and reducing fractions to a common denominator we have

$$R = \frac{1}{S}, \quad L = \frac{\nu(X)}{S}$$

(that is the desired values $\nu(X)$ is the numerator of L and S the denominator of R).

For $X = acaba$ this algorithm is traced as

```

L = 0, R = 1
x1 = a: L = 0 + 1·0 = 0, R = 3/5
x2 = c: L = 0 + (3/5)(3/4) = 9/20, R = (3/5)(1/4) = 3/20
x3 = a: L = 9/20 + (3/20)·0 = 9/20, R = (3/20)(2/3) = 1/10
x4 = b: L = 9/20 + (1/10)(1/2) = 1/2, R = (1/10)(1/2) = 1/20
x5 = a: – (L and R do not change since p(x5) = 1)
R = 1/20, L = 10/20

```

which gives, as it must be, $S = 20$, $\nu(X) = 10$.

Let us show without formal description but rather with the aid of example, how the enumeration helps to obtain an ideal cipher by applying the approach from [5]. Encode the message X by a three-part code in the following way. First write the counters n_a, n_b, n_c using an appropriate encoding. Then divide the whole set $C(X)$ into the subsets whose cardinality are powers of two. In our case we have two subsets with first 16 and last 4 elements. Enumerate them as 0 and 1, respectively. The second part of the code is the number of the subset that contains the message (0). Finally, convert $\nu(X)$ into the number within the subset and encode it with the number of bits corresponding to its cardinality (4 in our case). So we have:

$$X = acaba \rightarrow 311\ 0\ 1010.$$

The last code component (1010 in binary) is indistinguishable from a completely random 4-bit sequence and it is the one to be encrypted with the secret key. After encryption it turns into a different number within the selected subset, say, 0110. The first two parts of the code are transmitted in the clear. So the adversary has 16 variants of decryption, all of which are equally likely.

To decrypt the message we first apply the secret key to recover the correct code. Then, having the counters, we compute S and initial cumulative distribution, from the last two code parts reconstruct $\nu(X)$, and obtain the fraction $V = \nu(X) / S$. Now we find a letter whose interval contains V . It is the first decoded letter. Then we reproduce operations of encoder (starting with $L = 0$ and $R = 1$). In the second and subsequent steps, we must take into account that the interval over which the letters of the alphabet are distributed shifts and narrows. Therefore, to search for a letter in the cumulative distribution, we must, as it were, reverse the process by calculating the value $\nu = (V - L) / R$. The letter whose interval contains ν is the next decoded. And so on, until n letters are decoded.

In this paper we introduce the idea of transformation rather than encoding. In our example (where 1010 changes to 0110 due to encryption) the process looks like

$$X = acaba \rightarrow abaac.$$

Enumeration and denumeration are executed as an inner algorithm that uses the same data structures for efficiency.

III. MARKOV CASE

Let there be given a stationary and ergodic Markov source of order m generating letters over the alphabet $A = \{a_1, a_2, \dots, a_N\}$. In such Markov source the probability of each symbol depends on m preceding symbols which form a context or, equivalently, a state of the source. Let us write the symbols of a state from left to right. Given a state $s = s_1 \dots s_m$, $s_i \in A$, the next source symbol is generated under a conditional probability distribution $p(a_i | s) = p(a_i | s_1 \dots s_m)$, $a_i \in A$, $i = 1, \dots, N$. The source is uniquely defined by conditional distributions for all possible states. However, we consider the case where all these distributions are unknown.

Let the source message be $X = x_1 x_2 \dots x_n$, each $x_i \in A$. The first m symbols do not have sufficient contexts to determine a state but this is not need in our design. Denote by n_{su} , where state s with letter u extend from $a_1 \dots a_1$ to $a_N \dots a_N$ (each $m+1$ symbols long), the number of times the state s followed by the letter u occur in X .

Consider an example. Let $A = \{a, b\}$, $m = 1$, and the message $X = abbababaab$. Then $n_{aa} = 1$, $n_{ab} = 4$, $n_{ba} = 3$, $n_{bb} = 1$.

The class of equally probable messages which we denote by $C_m(X)$ contains all combinations of n symbols that have the same set of counters n_{su} . Enumeration of the whole class, as described in [13], may require to walk through all N^m states for each message symbol. Even for short example above, it is not so simple to devise any other message containing the same set of pair counters. To reduce complexity, we suggest to split the message into a number of

memoryless sequences (the technique well-known in source coding).

The splitting is done as follows. Fix the first m message symbols. List in lexicographic order the contexts (states) that appeared in the message. Starting from $m+1$ th symbol, distribute the symbols from the message to the correspondent contexts. Now each context gathers a memoryless sequence of message symbols associated with that context.

Continue the above example. Fix the first letter a . Distribute all remaining letters to two contexts:

$$\begin{aligned} a: & \text{bbbab} \\ b: & \text{baaa} \end{aligned}$$

From this splitting we can recover the initial message. Write the fixed letters and select the corresponding context. Extract the first letter from this context and put it in the message. The letter forms a new context in the message. Find this context in the context list and continue the process of extraction and putting in the message until all contexts become empty.

As soon as we split the Markov source message into a number of memoryless sequences where all symbols are statistically independent, it may seem that we can apply to these sequences the approach that we used for enumeration of memoryless source messages. Recall that this approach was based on observation that all combinations with the same number of individual letters were equally probable. But here we have an obstacle. We can show with an example that not any combination of letters in the split sequences admits reconstruction of a message. For instance, the following permutation:

$$\begin{aligned} a: & \text{bbbba} \\ b: & \text{aaab} \end{aligned}$$

cannot be reconstructed. Starting with a , we write $abababb$ and remain in state b from which there are no more transitions to state a . In state a one letter remains unused and the reconstruction fails. It shows that memoryless sequences are not completely independent from each other.

Fortunately, for first-order Markov sources in [14] and then for arbitrary order sources in [15], it was shown that the dependence, in fact, is hidden in the last symbols. If we leave the last symbols of all memoryless sequences intact, any combinations of preceding letters become acceptable. For example, the following permutation:

$$\begin{aligned} a: & \text{babbb} \\ b: & \text{abaa} \end{aligned}$$

is reconstructed as $abaabbabab$ which is of the same probability class as the initial $abababaab$ (the counters n_{su} are the same).

Now we are ready to describe the suggested algorithm of enumeration. Denote by $X[i:j]$ a fragment of X starting with character x_i and ending with character x_j . Define a data structure Ordered Context List (OCL). OCL can be implemented as a binary search tree whose nodes store the contexts and associated strings of message symbols that appear in those contexts. Traversing the tree from left to right gives the contexts in lexicographic order. For algorithm description, denote the current context in OCL by cc , and the corresponding string of message symbols by str_{cc} . Enumeration of message X consists of two stages: the first stage performs splitting and the second computes the ordinal

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Methodology of Complex Steganalysis Using Image Quality Characteristics Estimation

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Abstract—The paper presents a methodology for complex steganalysis that takes into account the quality characteristics of the analyzed image. The proposed method improves the accuracy of the joint application of statistical steganalysis methods, mainly by reducing false-positive results.

Keywords— *steganalysis, steganography, quality characteristics, binary classifier.*

I. INTRODUCTION

The threat of attackers using steganographic embedding techniques in image files to deliver malicious data inside attacked systems is growing in urgency [1]. The greatest risks in this context relate to systems related to the processing and storage of graphic information - for example, vision systems, monitoring and visualization systems for autonomous and unmanned vehicles, corporate systems for processing and storing documents.

The typical scenario of steganography being used by attackers is its use as part of the implementation of malicious loaders such as IDAT Loader, Zero.T and their like [1]. They are the auxiliary means that ensures «infection» - invisible penetration of malicious code inside the attacked system and ensuring its ability to launch. Thus, the use of steganography and the organization of a glass channel is part of the activities to organize a reliable and safe from the point of view of attacker's way of transmitting malicious information.

The most frequent method of steganographic embedding of data into images used by attackers as part of cyberattacks is the method of hiding pixel color intensity (luminance) estimations in the Least Significant Bits (LSB) [1].

II. METHODOLOGY OF COMPLEX STEGANALYSIS

Currently, there are two main approaches to the development of steganalysis methods [2]:

1. The use of artificial convolutional neural networks (CNN).
2. The use of binary classifiers, including those based on extensive feature spaces and the ensemble approach.

The first approach is more actively developed today, but it does not always guarantee higher accuracy of steganography detection with more complex computational implementation of the steganalytical system (in particular, in the issues of training and retraining of the neural network) and less interpretability of the results [2].

This paper proposes a method of complex steganalysis of embedding in LSB based on the second approach: selecting a set of meaningful features and training a binary classifier to solve the problem of distinguishing between filled and empty

stego-containers. Complex steganalysis includes the results of statistical steganalysis methods as well as additional computable or intrinsic image features and parameters.

Based on the chosen approach, it is possible to formalize the methodology of complex steganalysis in the form of an algorithm for implementing the steganalysis method:

1. The choice of statistical methods of steganalysis that form a numerical estimation (estimates of the relative amount of hidden information or another estimation that determines the estimated probability of hidden information) or a binary detection estimate (whether hidden information is present in the image) and the calculation using the selected methods.
2. The choice for a set of additional characteristics and attributes:

- intrinsic to the
- calculated on the basis of image data (e.g., various statistical characteristics of the image not directly related to steganalysis tasks).

Calculation of the estimations of the selected computed features.

3. Classification of the stego-container of the analyzed image using a pre-trained binary classifier based on a set of features including all estimations from steps 1 and

III. SELECTION OF FEATURES FOR COMPLEX STEGANALYSIS

The paper [3] demonstrated the existence of statically significant correlation between the magnitude of error in estimating the relative amount of hidden information for empty containers by Chi-Square Attack (CSA) [4,5] and Regular-Singular (RS) [6] methods and a number of absolute quantitative estimates of qualitative image characteristics: noise, sharpness, blurriness, contrast, Shannon and Renyi entropy.

The choice of the above-mentioned characteristics is conditioned by the hypothesis formed in the course of solving practical problems on detection of steganographic embedding in graphic files about deterioration of steganalysis accuracy for images that can be characterized as “low-quality” during visual inspection. The work [3] demonstrates, using several examples, how a noticeable visual deterioration of image quality correspondingly affects the quality scores generated by the chosen algorithms for their calculation: the scores by CSA and RS methods turn out to be noticeably higher for, for example, “blurred”, “grainy” and overexposed images.

To further confirm the influence of visually perceived image quality on the accuracy of steganalysis methods, a study of the relationship between quality scores and errors in estimating the relative amount of hidden information by CSA and RS methods for filled containers was conducted. A sample of 16,614 PNG-24 files was prepared. For all images, qualitative characteristics were calculated. After that, three subsamples were formed:

- PERFECT (images with low noise and blur scores, high sharpness and entropy scores),
- NORMAL (images with low or medium noise and blur scores, medium or high sharpness and entropy scores),
- BAD (images for which at least two low quality conditions are met: high noise, high blur, low sharpness, low entropy).

Contrast estimation was not taken into account, as there is no obvious or visually intuitive criterion for assigning it to the fuzzy estimation of “bad” or “good” [7]. The k-means clustering method (k-means++) is used to perform fuzzy classification of grade levels (high, medium, low) [8].

For all images of each of the three samples:

- the mean errors in the estimation of the relative volume of hidden information by CSA and RS methods with an empty container were calculated;
- hiding of information of different volumes in LSB was performed first sequentially, then pseudorandomly;
- average estimations of errors in estimating the relative volume of hidden information by CSA and RS methods for both variants of filled containers were calculated;
- calculated mean estimations of errors in estimating of CSA and RS for both variants of filled containers for each range of relative volume of really embedded information: [0%-10%, ..., 90%-100%].

To determine the influence of image quality on the results of steganalysis methods, let us consider the obtained errors in estimation in determining the relative amount of hidden information: they are presented in Figures 1-4.

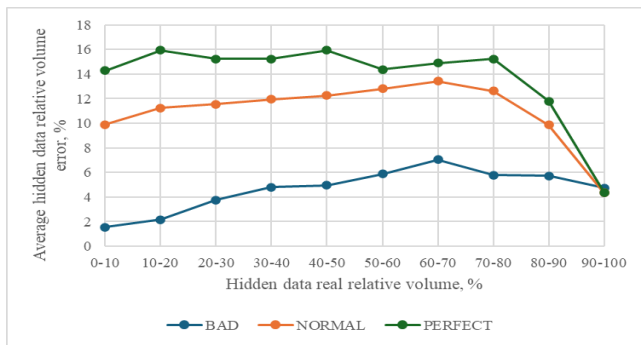


Fig. 1. Comparing the mean deviations of the CSA method for sequential embedding

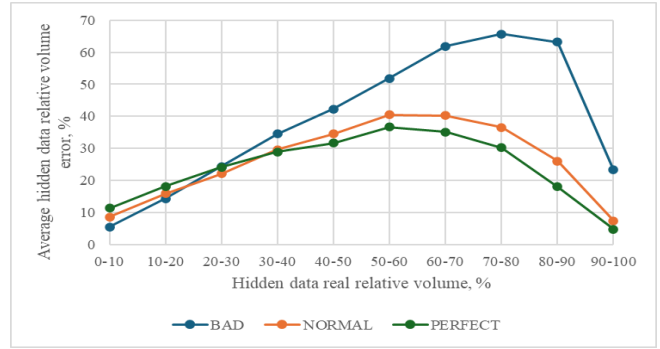


Fig. 2. Comparing the mean deviations of the CSA method for pseudorandom embedding

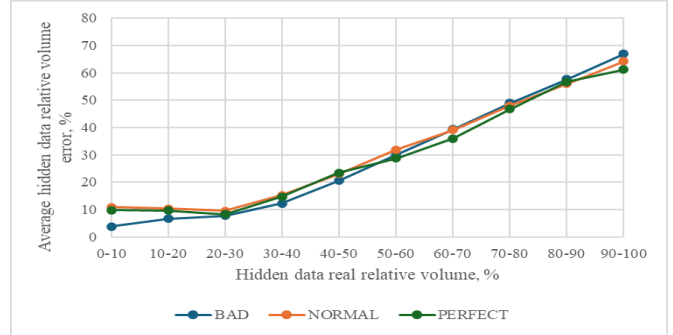


Fig. 3. Comparing the mean deviations of the RS method for sequential embedding

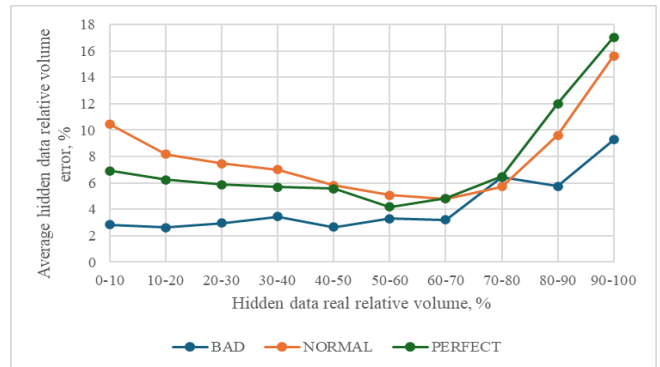


Fig. 4. Comparison of mean deviations of the RS method in pseudorandom embedding

On the basis of the results obtained, it can be concluded that image quality has an impact on the accuracy of steganalysis by CSA and RS methods for filled containers (except for the analysis of the container with sequential embedding by RS method).

The discovered dependence is also confirmed by the results of Spearman's correlations calculation (Student's t-criterion [9] is used to calculate statistical significance, Cheddock's scale [10] is used to estimate the correlation strength) between the error estimation in estimating the relative amount of hidden information by the corresponding steganalysis methods and the estimations of the considered absolute qualitative characteristics of the image (Tables 1-4).

TABLE I. CALCULATING OF THE CORRELATION BETWEEN THE ERROR OF THE CSA METHOD AND ESTIMATES OF QUALITATIVE CHARACTERISTICS IN SEQUENTIAL EMBEDDING

	Correlation coefficient	t-criterion estimation	Is the correlation significant?	Degree
Noise	0,295	34,91	yes	low
Sharpness	0,294	34,85	yes	low
Blur	-0,453	-57,46	yes	moderate

	Correlation coefficient	t-criterion estimation	Is the correlation significant?	Degree
Contrast	-0,053	-6,05	yes	low
Shannon	0,17	19,56	yes	low
Renyi	0,173	19,89	yes	low

TABLE II. CALCULATING THE CORRELATION BETWEEN THE ERROR OF THE CSA METHOD AND ESTIMATES OF QUALITY CHARACTERISTICS IN PSEUDORANDOM EMBEDDING

	Correlation coefficient	t-criterion estimation	Is the correlation significant?	Degree
Noise	-0,131	-14,93	yes	low
Sharpness	-0,107	-12,20	yes	low
Blur	0,15	17,21	yes	low
Contrast	-0,023	-2,59	yes	low
Shannon	-0,1	-11,42	yes	low
Renyi	-0,102	-11,54	yes	low

TABLE III. CALCULATING THE CORRELATION BETWEEN THE ERROR OF THE RS METHOD AND ESTIMATES OF QUALITY CHARACTERISTICS IN SEQUENTIAL EMBEDDING

	Correlation coefficient	t-criterion estimation	Is the correlation significant?	Degree
Noise	0,078	8,901	yes	low
Sharpness	0,067	7,452	yes	low
Blur	-0,091	-10,288	yes	low
Contrast	-0,029	-3,375	yes	low
Shannon	0,008	0,949	no	—
Renyi	0,008	0,932	no	—

TABLE IV. CALCULATING THE CORRELATION BETWEEN THE ERROR OF THE RS METHOD AND ESTIMATES OF QUALITY CHARACTERISTICS IN PSEUDORANDOM EMBEDDING

	Correlation coefficient	t-criterion estimation	Is the correlation significant?	Degree
Noise	0,318	37,96	yes	moderate
Sharpness	0,349	42,10	yes	moderate
Blur	-0,467	-59,72	yes	moderate
Contrast	0,026	2,89	yes	low
Shannon	0,173	19,87	yes	low
Renyi	0,169	19,39	yes	low

Beside absolute estimations of image quality characteristics, it is suggested to take into account the sensitivity of RS method to statistical anomalies in the frequency representation of the image (Table 5). Since the key task is the detection of embedding in the LSB, possible embedding or any other artificial distortions in the coefficients of the DCT matrices should be considered as additional disturbances affecting the accuracy of steganalysis by the RS method. In this regard, it is proposed to include in the resulting set of features the results of a simple steganalysis of possible embedding performed by the Koch-Zhao method in sequence.

TABLE V. EXAMPLES OF CHANGES IN RS METHOD SCORES WHEN HIDING DATA USING THE KOCH-ZHAO METHOD FOR A TEST IMAGE

Volume of information hidden by the Koch-Zhao method, bits	Estimation of relative volume of hidden information by RS method, %
0	3,46
426	4,03
822	5,16
2 484	9,66

As the results of steganalysis by the algorithm described in [11], it is proposed to select the estimated bit volume of embedded information and the estimated value of the embedding threshold for the generated feature set. Using both estimations will reduce the probability of false detection of embedding in the frequency domain. To signal the detection of such embedding, it is necessary to obtain both a relatively high estimated threshold value and a significant estimated bit-length of the hidden data.

Another significant factor is the direction of traversal of the pixel matrix (or pixel blocks) during image embedding and steganalysis. Embedding in the LSB in the sequential version can be performed either by rows or columns of the pixel matrix. In the second case, the steganalysis accuracy of the CSA method, which traditionally uses row-by-row traversal, will be extremely low. In particular, when testing the previously described NORMAL subsample (and its variants, in which information embedding into the LSB was performed sequentially and pseudo randomly), the following average error values in estimating the relative amount of embedded information were obtained:

- 31.67% when hiding by columns and steganalysis by rows;
- 30.55% when hiding by rows and steganalysis by columns.

The similar errors in estimation for steganalysis by the above-mentioned sequential hiding detection algorithm implemented by the Koch-Zhao method are 48.66% and 49.34%, respectively.

Thus, in order to realize an effective comprehensive steganalysis, it is necessary to perform analytical algorithms, whose accuracy potentially depends on the way the pixel matrix is traversed sequentially, twice: row-by-row and column-by-column, and to consider both sets of results within the set of features under consideration.

Due to the fact that the basis of the proposed method of complex steganalysis is statistical methods and statistical characteristics, the accuracy of the obtained results can be affected by the volume of analyzed data - that is, in this case, the number of image pixels (and thus, in fact, its linear dimensions).

To confirm this assumption, the above-mentioned NORMAL subsample was used in three variants (without embedding, with sequential and pseudo-random embedding in the LSB). The correlation between the number of image pixels and the error in estimating the relative amount of hidden information by CSA and RS methods was calculated (Tables 6-8).

TABLE VI. CORRELATION COEFFICIENTS BETWEEN THE ERRORS OF CSA AND RS METHODS AND THE TOTAL NUMBER OF IMAGE PIXELS

Embedding	CSA error	RS error
No embedding	-0,498	-0,488
Sequential	-0,597	-0,086
Pseudorandom	0,137	-0,334

TABLE VII. THE STUDENT'S T-TEST ESTIMATIONS OF THE CORRELATION COEFFICIENTS BETWEEN THE ERRORS OF THE CSA AND RS METHODS AND THE NUMBER OF PIXELS

Embedding	CSA error	RS error
No embedding	-73,97	-71,97
Sequential	-79,17	-9,20
Pseudorandom	14,65	-37,71

TABLE VIII. THE DEGREE OF SIGNIFICANCE FOR THE CORRELATION BETWEEN THE ERRORS OF THE CSA AND RS METHODS AND THE NUMBER OF IMAGE PIXELS

Embedding	CSA error	RS error
No embedding	Moderate	Moderate
Sequential	Noticeable	Low
Pseudorandom	Low	Moderate

Thus, the number of pixels as an inherent characteristic of an image should be included in the feature set of a comprehensive steganalysis that combines statistical methods and features.

IV. BINARY COMPLEX STEGANALYSIS CLASSIFIER

The set of features taken into account by the proposed method of complex steganalysis includes:

- estimation of the amount of hidden information by the CSA method (horizontal traversal);
- estimation of hidden information volume by CSA method (vertical traversal)
- estimation of the amount of hidden information by the RS method;
- estimation of noise level;
- estimation of sharpness level;
- estimation of blur level;
- contrast level estimation;
- Shannon entropy.
- Renyi entropy;
- estimated concealment threshold according to the evaluation of the steganalysis algorithm of concealment performed by the Koch-Zhao method (horizontal traversal);
- the estimated bit length of the hidden data according to the Koch-Zhao steganalysis algorithm (horizontal traversal);
- estimated hidden data threshold according to the evaluation of the steganalysis algorithm of hiding performed by the Koch-Zhao method (vertical traversal);
- estimated bit length of the hidden data according to the evaluation of the steganalysis algorithm of hiding performed by the Koch-Zhao method (vertical traversal);
- number of image pixels.

In order to train the binary classifier, a sample of 29,856 image files of different size and quality was prepared. In 45% of the files the information of random size was embedded randomly (pseudo-randomly or sequentially - by rows or columns), in 10% random data were embedded by the Koch-Zhao method, in the remaining 45% no embedding was performed. To form the sample, we used datasets of images with pre-implemented embedding in LSB, high-resolution, natural and artificial, with initially different indices of qualitative characteristics: [12-16].

Training of a binary classifier using the ML.NET framework was performed [17]. 20% of randomly selected sample data was used as a validation dataset. The highest

accuracy during training, 0.9282, was demonstrated by the random forest model trained with the following hyperparameters [18]:

- number of trees: 137;
- maximum number of “leaves” of the tree: 356;
- percentage of attributes used in the construction of the tree: 80%.

Another non-overlapping sample was prepared for testing the model, which was compiled according to the same principles as the training sample. It included 2,642 images. The quality metrics of the tested model are presented in Table 9, Table 10, Figures 5 and 6 show the corresponding error matrix, ROC and PR curves.

TABLE IX. METRICS FOR THE QUALITY OF THE TRAINED MODEL

Metric	Estimation
Accuracy	0,947
Precision	0,959
Recall	0,941
F1 Score	0,95
AUC	0,985
AUCPR	0,989

TABLE X. ERROR MATRIX OF THE TRAINED MODEL

		Model estimation	
		Hiding is defined	Hiding is not defined
Real data	Hidden	1330	84
	Unhidden	56	1172

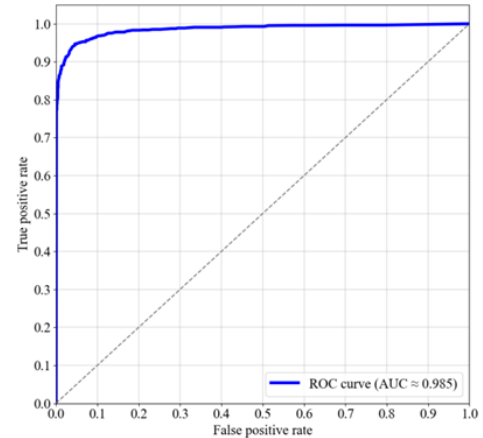


Fig. 5. ROC-curve

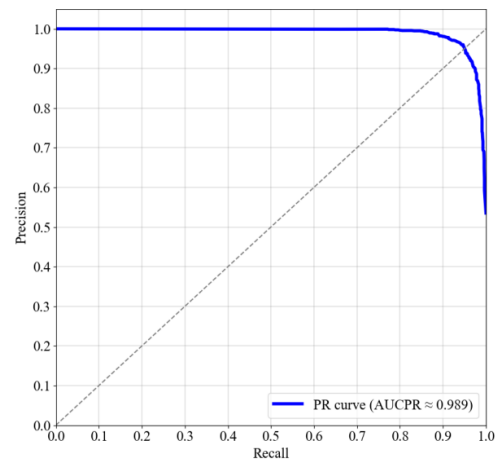


Fig. 6. Precision-Recall curve

In order to assess the significance of including selected additional features in the feature set for training, a number of additional random forest models were trained on the same dataset but with a truncated feature set. Their quality metrics are summarised in Table 11.

- (1): without quality characteristics.
- (2): without vertical traversals.
- (3): without considering the number of pixels.
- (4): without Koch-Zhao embedding steganalysis estimates.
- (5): only CSA and RS estimates.

TABLE XI. METRICS OF MODEL QUALITY WHEN TESTED ON A SAMPLE WITH EMBEDDING IN 2 LSB

	(1)	(2)	(3)	(4)	(5)
Accuracy	-0,04	-0,005	-0,014	-0,044	-0,057
Precision	-0,026	0,002	-0,023	-0,013	-0,08
Recall	-0,05	-0,013	-0,002	-0,075	-0,018
F1 Score	-0,039	-0,019	-0,013	-0,045	-0,049
AUC	-0,018	-0,06	-0,005	-0,02	-0,03
AUCPR	-0,015	-0,062	-0,005	-0,015	-0,027

The results confirm the significance of including the selected additional characteristics in the set of analyzed features within the framework of complex steganalysis.

Since, on average, the strength of correlation between quality scores and the error in estimating the relative amount of embedded information using CSA and RS methods is higher when analyzing empty containers than filled ones, taking into account these characteristics allows us to reduce the probability of false positive detection of steganography associated with poor image quality.

The trained model was tested on a sample composed similarly to the previous ones, when embedded in two LSBs instead of one. The quality metrics and error matrix of the tested model are presented in Tables 12-13.

TABLE XII. METRICS OF MODEL QUALITY WHEN TESTED ON A SAMPLE WITH EMBEDDING IN 2 LSB

Metric	Estimation
Accuracy	0,922
Precision	0,96
Recall	0,889
F1 Score	0,923
AUC	0,981
AUCPR	0,984

TABLE XIII. ERROR MATRIX OF THE MODEL WHEN TESTED ON A SAMPLE WITH EMBEDDING IN 2 LSB

		Model estimation	
		Hiding is defined	Hiding is not defined
Real data	Hidden	1 243	155
	Unhidden	57	1 187

In this case, the proportion of false positives was 57 images - about 2.16%. This is one image more than when the model was tested on a sample in which the embedding was performed in a single NCB. Thus, the model that takes into account the selected qualitative and additional characteristics is able to effectively resist false detection of low-quality images as containing embedded data.

V. CONCLUSION

The proposed method of complex steganalysis allows to form a conclusion about the presence or absence of steganographic embedding in the LSB of graphic files taking into account possible distortions in the estimates of statistical methods of steganalysis when working with low-quality images.

This method can be integrated into another ensemble steganalysis method as a component part or used to implement an independent separate steganalytical detector.

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Development of the Methodology for Automation of Access Control to the Resources of a Transport Enterprise

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Abstract — The main feature of the information environment of the transport enterprise is the heterogeneity of the subjects of requests to its resources. While the objects of information relations are the resources of the transport enterprise, the employees of the transport enterprise, its customers, and the equipment and materials suppliers are the subjects of information relations. In this regards, ensuring the access control to the resources of a transport enterprise is actual problem. The article is devoted to development of the methodology for automation of access control to the resources of a transport enterprise.

Keywords — automation, information protection, information security, access control, heterogeneous environments.

I. INTRODUCTION

Modern transport enterprises use heterogeneous information environment, provide services and products to other enterprises and individuals. Thus, the variety of objects and subjects of access determines the requirement for reliable mechanism of access control to the resources of a transport enterprise. The article is devoted to the development of a methodology for managing access to the resources of a transport enterprise, taking into account the heterogeneity and variety of subjects and objects of access, as well as the heterogeneity of the information environment of a modern transport enterprise.

The need to form a reliable mechanism of access control to the resources of a transport enterprise is due to several factors: the increasing number and complexity of attacks, including the Advanced Persistent Threat class of attacks (further – APT) [1-7], the heterogeneity of the external and internal information environments of a transport enterprise, the variety of access subjects and objects, the complexity of business processes and automated systems applied in the transport enterprise (including CAD, CAM, CAE, SCADA).

II. INTERACTION OF BUSINESS PROCESSES OF A TRANSPORT ENTERPRISE WITH THE EXTERNAL INFORMATION ENVIRONMENT

Figure 1 shows the scheme of the interaction of the transport enterprise processes with the external information environment. The diagram created by means of IDEF-concept [8-12].

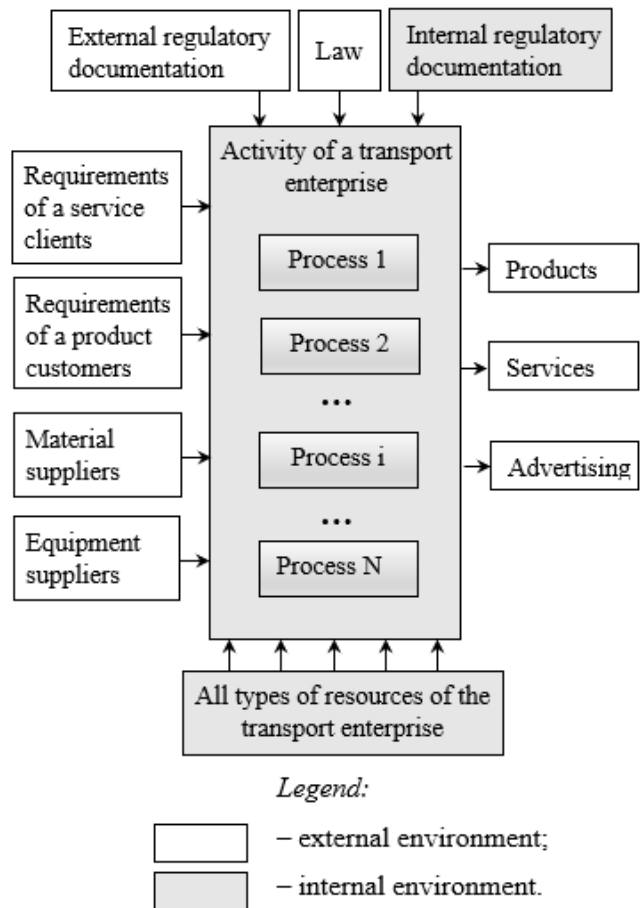


Fig. 1. Scheme of the interaction of the transport enterprise processes with the external information environment

According to Figure 1, the following relates to the enterprise's activity as a process:

- «Input»:
 - requirements of a service clients;
 - requirements of a product customers;
 - material suppliers;
 - equipment suppliers;
- «Control»:
 - law;
 - external regulatory documentation;
 - internal regulatory documentation;

- «Resources»: all types of resources of the transport enterprise;
- «Output»:
 - products;
 - services;
 - advertising.

Thus, the internal information environment of the transport enterprise includes:

- business processes of the transport enterprise;
- all types of resources;
- internal regulatory documentation.

The external information environment consists of:

- law;
- external regulatory documentation;
- requirements of service clients;
- requirements of product consumers;
- material suppliers;
- equipment suppliers;
- products;
- services;
- advertising.

III. CONCEPTS OF THE OBJECT AND SUBJECT OF ACCESS TO THE RESOURCES OF THE TRANSPORT ENTERPRISE

Figure 2 shows the scheme of interaction between access subjects and access objects.

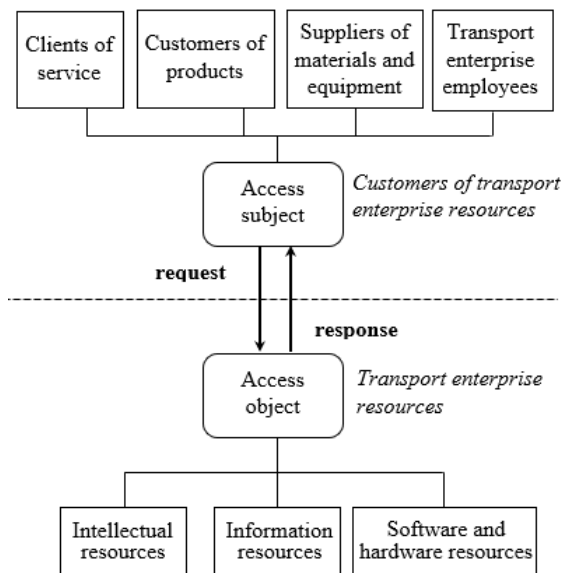


Fig. 2. Scheme of the interaction of the transport enterprise processes with the external information environment

According to Figure 2, the access subjects include:

- clients of services;
- consumers of products;
- suppliers of materials and equipment;

- employees of the transport enterprise.

Access objects include:

- intellectual resources;
- information resources;
- software and hardware resources.

It is precisely at the stage of forming a request from subject to object access and receiving a response should be the mechanism for access control to the resources of the transport enterprise.

IV. TYPES OF OBJECTS AND SUBJECTS OF ACCESS

The concept of information security of transport enterprise resources includes: confidentiality, integrity, accessibility [13-23]. Confidentiality of information resources divided into «secrecy» – confidentiality of information resources of a transport enterprise, «privacy» – confidentiality of personal data. Personal data, in turn, is the data of both employees of the transport enterprise and individuals who are clients of the transport company.

Figure 3 shows the scheme of the relationship of access subjects to the categories of objects «secrecy» – «privacy».

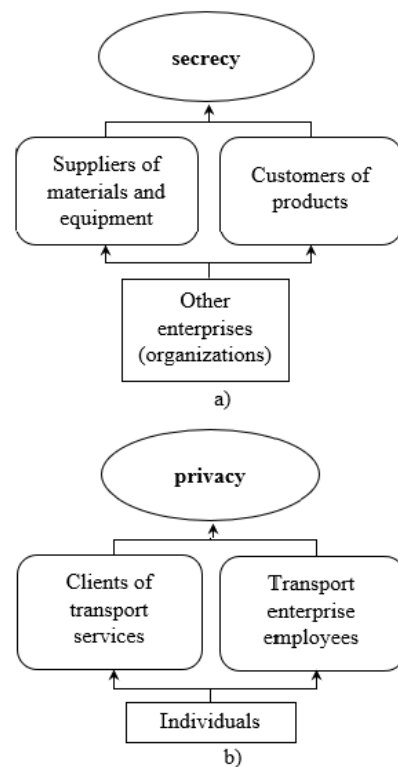


Fig. 3. Scheme of the relationship of access subjects to the categories of access objects «secrecy» – «privacy»

Thus, the category of «secrecy» access objects is relative to access subjects – other enterprises (organizations), and the category of «privacy» access objects is relative to access subjects – individuals.

V. LEVELS OF SEPARATION OF ACCESS OBJECTS ACCORDING TO THE GRADATION OF CONFIDENTIALITY OF BUSINESS PROCESSES

Figure 4 shows the scheme of the division of access objects – business processes – according to its confidentiality gradation.

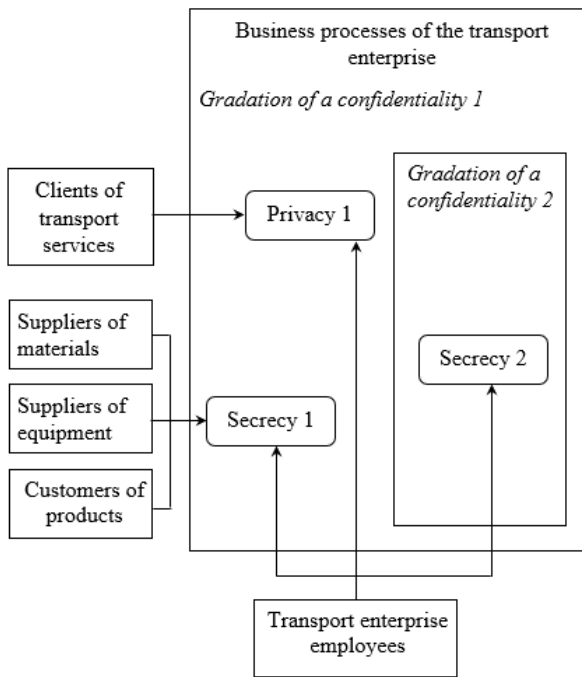


Fig. 4. Scheme of division of access objects – business processes – according to their confidentiality gradation

According to Figure 4, the business processes related to the category «Privacy 1» interact with access subjects: clients of transport services, employees of the transport enterprise. Bright examples of these processes are:

- booking tickets for clients of transport services;
- hiring a new employee to the staff.

The category «Secrecy 1» includes business processes in which access subjects are: material suppliers, equipment suppliers, product consumers, and transport enterprise employees. Bright examples of these processes are:

- processing an order for products;
- processing a request for the supply of materials;
- processing a request for the supply of equipment;
- processing a request for equipment repair, etc.

The category «Secrecy 2» includes business processes in which only one type of access subjects participates – employees of the enterprise. This category of access objects should include the most important business processes of the transport enterprise, for example, the processes of manufacturing products and documentation for it.

Unlike other types of access subjects, employees of the transport enterprise make requests to resources at each level of confidentiality gradation of access objects – business processes of the transport enterprise.

Thus, the gradation of confidentiality of information and intellectual resources is determined by their consumption by a particular business process. In other words, the gradation of confidentiality is assigned to the business process of a transport enterprise, and then the list of information and intellectual resources used in this process is determined.

Table 1 shows the correspondence between access subjects and resources of the transport enterprise (access objects). Table 2 shows the adjacency matrix of access subjects and access objects.

TABLE I. CORRESPONDENCE BETWEEN ACCESS SUBJECTS AND RESOURCES OF THE TRANSPORT ENTERPRISE (ACCESS OBJECTS)

Access subject	Access object
Clients of transport services	Information and intellectual resources of business processes of the category «Privacy 1»
Material suppliers	Information and intellectual resources of business processes of the category «Secrecy 1»
Equipment suppliers	
Product consumers	
Transport enterprise employees	Information and intellectual resources of business processes of the category «Privacy 1»
	Information and intellectual resources of business processes of the category «Secrecy 1»
	Information and intellectual resources of business processes of the category «Secrecy 2»

TABLE II. ADJACENCY MATRIX OF ACCESS SUBJECTS AND ACCESS OBJECTS

		Access object		
		Information and intellectual resources of business processes of the category «Privacy 1»	Information and intellectual resources of business processes of the category «Secrecy 1»	Information and intellectual resources of business processes of the category «Secrecy 2»
Access subjects	Clients of transport services	+		
	Material suppliers		+	
	Equipment suppliers		+	
	Product consumers		+	
	Transport enterprise employees	+	+	+

In this case, it is possible to use the discrete access control model described in works [13, 14, 23].

VI. THE ALGORITHM FOR GRANTING THE RIGHTS FOR SUBJECTS OF ACCESS TO THE RESOURCES OF A TRANSPORT ENTERPRISE

Figure 5 shows the scheme of the algorithm for granting the rights of subjects of access to the resources of a transport enterprise.

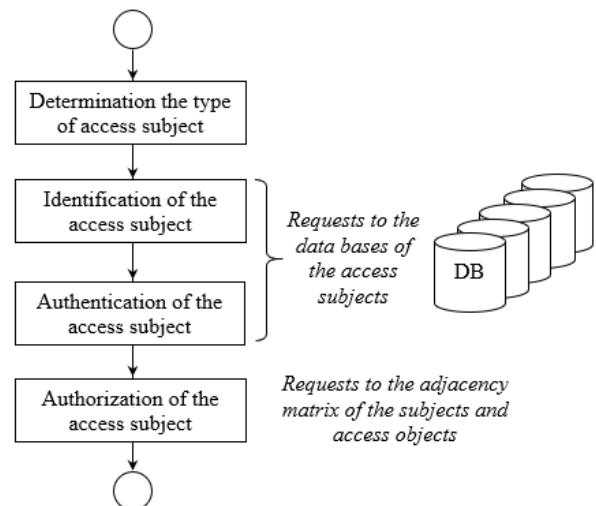


Fig. 5. Scheme of the algorithm for granting access rights to the resources of the transport enterprise

According to the algorithm shown in Figure 5, the first step is determination the type of access subject: the service

client, supplier, product consumer, or employee of the transport enterprise.

Next, the identification and authentication procedures are performed, during which requests to the relevant databases of access subjects are made.

At the final step, the authorization procedure for the access subject is performed – granting its rights, during which requests to the matrix of adjacency of subjects and access objects are made.

VII. IMPLEMENTATION OF THE METHODOLOGY FOR AUTOMATED ACCESS CONTROL TO THE RESOURCES OF A TRANSPORT ENTERPRISE

To implement the algorithm presented in the article, it is possible to use various authentication technologies: based on knowledge of a secret (password), based on possession of a material medium, biometric authentication, as well as remote authentication [13, 14, 22-25].

The choice of authentication technology depends on the type of access subject. In Table 3 recommendations for the use the authentication technologies depending on the type of access subject is shown.

TABLE III. RECOMMENDATIONS FOR USE THE AUTHENTICATION TECHNOLOGIES DEPENDING ON THE ACCESS SUBJECT

Access subject	Authentication technologies
Clients of transport services	Remote password, remote biometric, remote multifactor authentication
Material suppliers	
Equipment suppliers	
Product consumers	
Transport enterprise employees	Multifactor authentication, consisting of password authentication, authentication based on a material medium, as well as biometric (static and dynamic) authentication

VIII. CONCLUSIONS

During the development of a methodology for automated access control to resources of a transport enterprise, the authors of the article analyzed the interaction of business processes of the transport enterprise with the external information environment, considered the concepts of the access subject and access object, their types, and presented the levels of division of access objects according to the gradation of confidentiality of the business processes. The article also presents an algorithm for granting the rights of access subjects to the resources of the transport enterprise, and recommendations for the use of authentication technologies depending on the type of access subject.

The methodology presented in the article, designed to ensure automated access control to the resources of a transport enterprise, takes into account the variety of types of access subjects and the heterogeneity of the internal information environment of the transport enterprise.

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Advanced IT-Security Risk Assessment Methods for Critical IT Infrastructure Facilities

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Abstract— The present publication considers the practice of IT-security risk assessment for the CII facility, using the example of water supply management system at the enterprise, applying several methods: Event Tree Analysis (ETA), Fault Tree Analysis (FTA) and method of ISO/IEC 27005 standard. Scientific novelty is in supplementing the existing guidelines' requirements in the field of CII facilities security in the Russian Federation with the advanced methods of IT-security risk assessment, as well as in implementing the existing audit processes. Artificial intelligence risks to be taken into account when developing new (prospective) IT-security systems for CII facilities are considered separately. The study uses the analysis of in-house and foreign scientific publications, structural analysis, system analysis and cutting-edge management standards which can be implemented to assess IT-security risks at CII facilities. The most valuable results are the practical outcomes of solving a specific problem - implementation of state-of-the art methods of IT-security risk assessment at CII facilities in addition to the current standard requirements in the Russian Federation.

Keywords—critical infrastructure, critical infrastructure facilities, information security, standard, risk, risk assessment, countermeasures, residual risks, artificial intelligence risks

I. INTRODUCTION

The issue of ensuring security at critical infrastructure facilities (hereinafter - CII) is not a new one; the Russian Federation is aware of the requirements developed by various regulators (for example: FSTEC Order No. 235, 239, etc.). However, the applicable regulatory database does not consider the full cycle of risk management, in particular, the Methodology for Assessing Threats to Information Security approved by the FSTEC of Russia on February 5, 2021 (see p. 2.3; p. 2.7; p. 3.2) specifies a complicated and controversial «replacement» of the term «damage» by the term «risk», but the practice of assessing the effectiveness of security measures and residual risk calculation in a full closed cycle is not given.

Another methodological document Methodology for assessing the indicator of the state of technical information protection and security of significant objects of critical information infrastructure of the Russian Federation, approved by the FSTEC of Russia on May 2, 2024, provides a list of private security factors, their names and maximum values, but only in relation to ensuring the security of CII facilities from relevant Information Security Threats. Unfortunately, the risks (residual risks) are not considered in the mentioned document.

Due to the omission of the risk assessment stage after determining the relevant Information Security Threats and passing directly to the selection of security means, the process of ensuring the security of CII facilities is objectively

incomplete. It seems reasonable to improve the accuracy and speed of assessment of the CII facilities current level of security by supplementing the existing methodological requirements with suitable risk assessment methods.

The purpose of the study is to compare the methods of IT-Security risk assessment for solving a certain practical task - ensuring the security of a particular CII facility. As a result of the comparison, quantitative risk assessments for a specific CII facility were obtained, which can be independently reproduced by other researchers for similar CII facilities

II. ANALYSIS OF KNOWN RISK MANAGEMENT METHODS

The scientific literature provides enough examples of the utilization of contemporary national and international standards of risk management, including the practice of CII facilities security. For example, there are notable works [1,2,3], and the SolarWind attack incident is also known.

This publication covers a practical target - the comparison of several methods of IT-Security risk assessment using a specific example of a CII facility - a water supply control system of an industrial enterprise based on an Programmable logic controller (hereinafter - PLC) within the framework of solving a complex security problem. The type of this CII facility is chosen not accidentally, the issue of security of water supply control systems is recognized as relevant and such CII facilities, as a rule, are characterized by high complexity (for example, more than 512 parameters per 1 technological unit).

Public resources of in-house PLC developers (for example, DevLink-C1000 of NPF Krug or AR-8 of Kaskad) provide some technical information, but there is no data on reliability (Mean Time Between Failures, MTBF), risk level (Safety Integrity Level, SIL). Some parameters are partially specified (for example, for Tornado-N PTC the Mean Time Between Failures is specified as 150 thousand hours) or information on previously implemented projects based on foreign PLCs (only SIL 2 is specified). We note that SIL 2 corresponds to the target failure rate (risk for CII facility) in the range from 10^{-3} to 10^{-2} according to IEC 61508.

It is proposed to solve the practical task for a specific CII facility on the basis of a number of standards:

- «comprehensive» risk management standard ISO 31000:2018;
- «special» standard IEC 31010:2019.

The following explanations are important:

- frequently topical methods of IT-Security risk assessment remain unknown for application due to

various reasons, e.g., they are excluded during studying in higher education institutions, they are not considered at specialized programs of additional education, due to formal approach to the application of «paper» security and so on. [4,5];

- additional methods of SIL estimation for CII facilities are not covered by this publication, the detailed risk analysis methodology and formulas are given in IEC 61508, some estimation examples are provided in [5];
- herein ISO international standards are reviewed, since in general they have significant novelty in comparison with national standards of GOST R system in the Russian Federation [6].

It is crucial for the present publication that the above editions provide exactly the «engineering» level of application of multiple risk management methods (for example, IEC 31010:2019 has more than 40), rather than generalized «sciolistic» structures [5]. In order to start assessing IT-Security risks at CII facilities, let us briefly review the available statistics on the causes, sources, and factors of such risks.

For example, the Security Navigator review presents data for 2024, structured by several analytical sections, which will be further required in the assessment of IT-Security risks. A «classic» analysis - traceability «from the asset» for ISO standards is also presented (see Fig. 1) The value of this example lies in the specific values assigned to each category («Asset», «Actions», «Violators»). It is very important to note, in particular, the accuracy of the categories: «internal violators», «external violators», «partners» and «others».

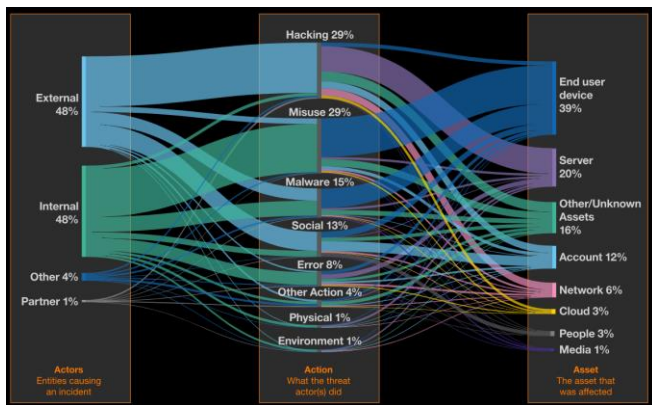


Fig. 1. Distribution by attackers, actions and impacted assets (source Orange Cyberdefense)

A helpful detailed breakdown by type of action should also be noted, which is generally in line with ISO/IEC 27005:2025 and can be practically applicable when assessing risks for CII facilities (e.g., environmental and/or physical impacts of partners). Despite the minimal levels of statistical impact (1% each) exactly such attacks, as the global practice of the largest intrusions (e.g., Schneider Electric, Colombian Pipeline) lead to significant damage.

III. INNOVATIONS IN THE FIELD OF RISK MANAGEMENT

There are two innovative proposals in the field of IT-Security risk management which seem to be very promising:

- The UK has proposed a classification of cyber incidents similar to natural disasters. The classification is based on 2 key factors: the number of entities «affected» by the incident and financial losses exceeding £1,000. Key factors to analyze include

business idle time, cost of data recovery, response costs, etc. However, fines, compensation and other fees are not included in the basic assessment.

- Phase 1 of artificial intelligence (hereinafter - AI) regulation has entered into force in the European Union, and accordingly, systems which entail «unacceptable risk» are prohibited as of February 2, 2025. The «unacceptable risk» includes, inter alia: implementation of vulnerabilities for employees, social scoring for private (public) purposes, individual predictive analytics based on employee profile, biometric classification based on nationality, trade union membership, political commitment, religion and etc.

Noteworthy, the European Commission envisages the introduction of special standardization measures in the field of AI, which are supposed to ensure the standardization of a number of standards (in particular, CEN and CENELEC). In general, this practice is known, both for ISO standards and for other methodological documents, such as Cobit. It is expected that once the new standards are published in the Official Journal, there will be a «presumption of conformity» to the established requirements for all AI systems under development.

IV. THE MAIN RESULTS OF IT-SECURITY RISK ASSESSMENT

To assess IT-Security risks for a specific CII facility, 3 methods are analyzed:

- quantitative Event Tree Analysis (ETA) method according to IEC 31010:2019 requirements;
- quantitative Failure Tree Analysis (FTA) method according to IEC 31010:2019 requirements;
- quantitative method for risk assessment in compliance with ISO/IEC 27005:2022 requirements.

Herein we briefly explain the choice of these methods for solving the practical objective of IT-Security risk assessment for a specified CII facility:

- all reviewed methods provide the possibility of obtaining quantitative estimates of IT-Security risks, it is precisely such estimates which are convenient to compare with the amount of potential damage, security budget and criteria for IT-Security risk acceptance (processing);
- other available methods (e.g. Markov analysis or Monte Carlo method), which also operate with quantitative risk assessments (see Table A.2 of IEC 31010:2019), but are more oriented on the estimation of probabilities, require significantly higher costs of expertise and processing;
- all of analyzed methods ensure reproducibility and repeatability, which is crucial for performing testing and comparing with numerical results of outdoor testing by in-house team of IT-Security experts.

V. COMPARISON OF IT-SECURITY RISK ASSESSMENT METHODS FOR CII FACILITIES

Based on the requirements of IEC 31010:2019 (ETA and FTA respectively) and ISO/IEC 27005 standards, as well as the author's practices [4,5,6], we will compare the methods of IT-Security risk assessment applied to a specific CII facility (advantages and disadvantages), with the results in Table 1.

TABLE I. COMPARISON OF IT-SECURITY RISK ASSESSMENT METHODS FOR CII FACILITIES

Method	Description	Advantages	Disadvantages
ETA (IEC 31010)	The model is based on possible outcomes from input events and status of security measures, which are analyzed in terms of probabilities and frequencies	<ul style="list-style-type: none"> Shows the impact of ineffective monitoring measures in the diagram format; Identifies potential failures, insecurities, and low inefficiency security measures; Considers timeframes and the «domino effect» 	<ul style="list-style-type: none"> To perform a complete analysis, it is necessary to identify all possible initial events; Only the states of successful operation and system failure are processed, and it is difficult to take into account partially working elements (protection measures)
FTA (IEC 31010)	The model is based on variant analysis using Boolean logic to determine the combination of failures. Variants include a success tree with prioritized events and a fault tree applied to investigate events	<ul style="list-style-type: none"> It is characterized by a systematic approach and allows for the analysis of many factors; Logical fault tree analysis is useful in identifying the failure paths of components in a complex system 	<ul style="list-style-type: none"> The method operates only with binary states; The method analyzes one main event and does not take into account secondary or accidental failures; For large - scale systems, the structure can be very complex
Risk management (ISO/IEC 27005)	The model is based on the implementation of the 'classical' sequence: establishing the context (including criteria), risk analysis (including identification), risk assessment, risk processing and risk acceptance.	<ul style="list-style-type: none"> Pre-defined catalogues of typical Information Security Threats and vulnerabilities Probability and damage assessment scales are available to generate a risk value A concise risk management structure with two benchmarks 	<ul style="list-style-type: none"> The method does not take into account the dependencies (sequence) of controls; For large - scale systems, the resulting numerical estimates can be very complex and cumbersome.

Based on the requirements of the IEC 31010:2019 standards (ETA and FTA, respectively) and ISO/IEC 27005, as well as the practice of the author [4,5,6], we compare

methods for assessing IT-security risks according to the criteria of practical (CII audit) Applicability and Repeatability, the results are shown in Table 2.

TABLE II. COMPARISON OF IT-SECURITY RISK ASSESSMENT METHODS FOR CII FACILITIES

Method	Practical (CII audit) applicability	Repeatability
ETA (IEC 31010)	<ul style="list-style-type: none"> For categorizing CII Facilities objects For IT-security audits For Functional safety audits (SIL based) 	<ul style="list-style-type: none"> Ensured by another team - by in-house experts or external audits. Additionally, benchmarking with the manufacturer's SIL data, received at the stand is possible
FTA (IEC 31010)	<ul style="list-style-type: none"> For categorizing CII Facilities objects For IT-security audits For Functional safety audits (SIL based) 	<ul style="list-style-type: none"> Provided by another team - in-house experts or external audits. Additionally, it is possible to compare with the manufacturer's data (SIL) obtained at the stand.
Risk management (ISO/IEC 27005)	<ul style="list-style-type: none"> To account for incidents, Threat database and risks according to requirements (FSTEC database, OWASP, MITRE ATT&CK, etc.) For categorizing CII Facilities objects For IT-security audits For Functional safety audits (SIL based) 	<ul style="list-style-type: none"> Provided by another team - in-house experts or external audits. Additionally, it is possible to compare with audit data for ISO/IEC 27001 certification.

VI. CONCLUSIONS

The present publication addresses the practical objective of IT-Security risk assessment at a particular CII facility in the general framework of solving the complex challenge of ensuring CII security on the basis of several methods of IT-Security risk assessment. The solution to this problem is proposed on the basis of several advanced methods of IT-Security risk assessment in addition to the applicable methodological requirements in the Russian Federation.

All the reviewed methods allow to objectively justify quantitative assessments of IT-Security risks and accurately generate a list of necessary security measures to ensure a given level of residual risks. The obtained outcomes can be applied by owners of CII facilities interested in ensuring a given level of security on the basis of cutting-edge IT-Security risk management methods that provide comparable and reproducible results.

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“Digital Audit” System Usage in Assessment the Company’s Security System Performance

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Abstract—This publication addresses the issue of optimizing the current practice of management systems auditing security. The importance of this challenge is determined by the known contradictions between the requirements of existing standards (e.g. ISO/IEC 27001 series) and different stakeholders’ expectations. Interesting discussion among expert auditors motivated by dynamic rather than fixed “paper” audits and top management committed to achieving the effectiveness of their own safety management systems is currently underway. The publication presents the results of practical testing of a system of “digital audits” for a large company, which is supported by unbiased data. The system of “digital audits” is characterized by a faster feedback cycle, application of numerical metrics and flexible (dynamic) process of considering the criteria, audit evidence and evaluation of corrective actions. The scientific novelty lies in proposing a closed-loop system of internal audits providing fast feedback and a uniform comparable assessment for different stakeholders. The obtained outcomes may be of interest to experts of certifying authorities performing safety management system audits in accordance with the requirements of both - national and global standards.

Keywords— *management system, process, internal audits, performance assessment, risks, standard, metrics, PDCA cycle, digital transformation, digital audits*

I. INTRODUCTION

Analysis of the management system performance assessment issue starts with statistics, which will allow us to understand which of these systems are objectively in demand and what are the dynamics of changes in the “need” of business in a particular service. The review “Statistics on Certificates. Analysis of The ISO Survey - 2018” report provides data for 2018, in particular, there is a decrease in the number of certifications in line with standards, respectively: ISO 9001 - minus 17%, ISO 14001 - minus 15%, ISO 27001 - minus 14%, ISO 50001 - minus 16%. On the contrary, the overview “Current Trends in Valid Certifications and Certified Sites” for the period 2018 - 2022 shows a constant global growth of certification according to ISO 9001, 14001, 27001, etc.

In the Russian Federation, the dynamics on ISO 9001 certification is an alternating quantity, for example, a significant decrease in certification was recorded in 2019 - 2018 (4134 and 4497 certificates respectively), in 2021 - 2020 (4313 and 5829 certificates respectively), in 2022 - 2021 (2619 and 4313 certificates respectively).

The existing system of certification of management systems based on ISO/IEC 17021-1:2015 Conformity assessment - Requirements for bodies providing audit and certification of management systems. Part 1: Requirements, of course, is a classic basic variant of the implementation of

audits. Definitely, this scheme is well known, has been practiced for many years and is convenient both for auditors (no need to go again tomorrow to check the effectiveness of treatment actions) and for organizations - a constant annual cycle allows “not to hand over tomorrow”. But the requirements for corporate governance tools, including management systems, are different in the actual business environment - owners require prompt execution of objectives and achievement of precise targets, i.e. a clear scale of allowable time for the decision generation and execution is imposed.

There are examples of digital transformation of well-performed “mainstream” business processes such as personnel audit, transaction analysis and monitoring, federal budget management, etc. in notable publications [1,2,3], which generally meets the current trend of the digital economy. The works of foreign scientists also present the research outcomes in the field of digital transformation of the internal audit sector [4,5,6].

However, the reviewed studies practically do not analyze the actual situation when a company is interested in a significant (by several digits) acceleration of its own management systems, generation of “digital audit” information systems (IS) ensuring fast feedback and operating with numerical performance assessment metrics. We propose the identification of the research task - to provide performance assessment of audits of management systems on the basis of the “digital audit” system.

II. THE CONCEPT OF "INSTANT AUDIT"

The concept of “instant” audits, i.e. audits performed beyond an annual cycle, was first presented in 2017 in the author’s PhD thesis. The concept was improved and presented in the author’s full thesis in 2018. Briefly, the basic idea is to reduce the time to perform audits when a given performance indicator (e.g., a target level of security metrics) is not achieved. The dynamic scheme of “instant audits” is presented in Fig. 1. This scheme suggests performing audits at the required frequency to achieve a target level of performance by certain metrics.

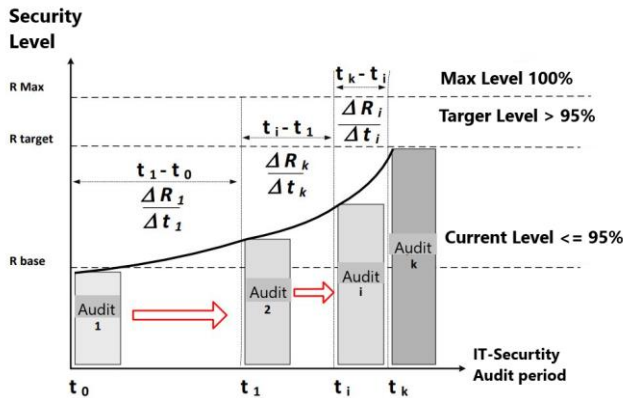


Fig. 1. Dynamic scheme of "instant audits"

Possible approaches to the current implementation of management system audits should be proposed in continuation of the concept:

- It is possible not to change anything - use a classical approach and comply with the requirements of ISO/IEC 17021 series and easily "stamp" audits on a set annual cycle, as it suits a known number of both clients and audit companies;
- It is possible to apply "business" approach and calculate the added value of the audit (e.g., by estimating time, finances, meeting business goals by service segment, product volume, etc.) ensuring the PDCA cycle "closing". Thus, the business receives a certain financial return at an approved time, and only when it is obtained, considers the ordered audit to be completed and effective.

The second approach is much more complicated, as it requires a certain business maturity: introduction of clear criteria, readiness for changes in the "vertical" management in the group of companies, availability of a comfortable IT management system for "digital audits", etc. The study of the set problem is in the focus of the second approach, which is confirmed by a number of publications [4,5,6].

III. THE PURPOSE OF CREATING A SYSTEM OF "DIGITAL AUDITS"

Establishing a system of "digital audits" for a group of companies entails the following objectives:

- to perform audits faster - audits at manufacturing enterprises are performed within 1 day according to predetermined criteria, as per the plan approved by a respective department;
- to perform audits at a lower cost - «on-site» audits are performed digitally, all deliverables are available to all stakeholders before the audit and are properly secured;
- to perform audits more precisely - an audit provides a quantitative assessment of compliance or non-compliance with established criteria (e.g.: actual values of readiness, level of availability of technical and human resources (THR), the degree of the daily and monthly work plan realization, etc.).

Obviously, only IT solutions make it possible to achieve the set goals.

IV. THE REASONS FOR USING THE "DIGITAL AUDITS" SYSTEM

Let us analyze several examples of practical implementation of the "digital audit" system at the manufacturing enterprises of a group of companies (in compliance with the accepted audit requirements for the confidentiality of all information obtained):

- Audit at site "A" showed that the work code RD 0092.XXX.XXX.XXX for 10.12.2023 was indicated as «idle time due to «Lack of DPL cable». An additional inquiry on the stock of inventory showed that such cables had been previously shipped from warehouse "N" only on 18.02.2023. Accordingly, the planned audit in December 2023 revealed a problem in the procurement and supply chains, however, if the audit had been conducted according to the dynamic scheme, the necessary corrective actions could have been implemented much sooner, not in 10 months. The measurement of losses in the "classical" audit method can be measured in hours of idle time, cost of labor time, or percentage of work plan failure.
- Under the actual bus traffic optimization model, "X" buses are needed at site "B" and idle time is not allowed at the "carousel" timing. The audit on 05.05.2024 showed that several buses were idle during the day, and corrective measures were determined for a period of 4 months. The next scheduled audit was carried out in November 2024 and revealed the following recurrent non-compliance: the number of buses exceeded the number by the optimization model. Indeed, the target "X" was achieved once in July, but subsequently the monitoring system showed a significant exceeding. See Figure 2 for an example of bus downtime at the facility.



Fig. 2. An example of bus downtime at a facility

It should be noted that the low coefficient of useful work of the actually used fleet of buses (see Figure 3). Indeed, with a deviation from the optimization model, the actual coefficient of useful work is significantly lower than planned and in the interval May – November 2024 did not exceed 36%. To put it simply, according to the monitoring system, the fleet of "X" buses was used only by a third.

Effective work, %



Fig. 3. The efficiency factor of the actually used bus fleet

- An audit of the inventory monitoring function at production facility “A” revealed the fact of a defective flange 150-16-11-1-V GOST 33259-15, steel grade 09G2S. The quality passport shows Brinell hardness (The Brinell scale, HB) 4.6. Similar passports of the same flanges show the correct hardness in the range of 131 - 156 (The Brinell scale, HB). The defective flange was removed from the pipeline and replaced with an acceptable one, then the full range of tests was repeated; accordingly, all corrective measures took several working days and required an extra labor payment for the personnel.

V. DIGITAL AUDIT METRICS

The following range of metrics is proposed for the “digital audit” system implementation (see Table 1).

TABLE I. DIGITAL AUDIT METRICS

Metrics	Analytical formula	KPI	Stakeholders
Audit program implementation	Ratio of audit checks completed on time to audits planned (excluding unscheduled audits)	100 %	Group of Companies Subcontractors
Replication of identified nonconformities	The ratio of the quantity of repeatedly determined nonconformities during a set period to the total quantity of nonconformities	0 %	Group of Companies Subcontractors
Impact on key figures	Ratio of the quantity of corrective actions within a set period to the quantity of deviations in the main production figures	0 %	Investor Group of Companies Subcontractors
Impact on start-up facilities	Ratio of the quantity of corrective actions within a set period to the quantity of deviations of values for start-up facilities	0 %	Investor Group of Companies Subcontractors

Presented set of metrics appears to be the most efficient in terms of compliance with the requirements of international standard ISO/IEC 17021 series, consideration of business requirements in terms of monitoring the key performance indicators of construction companies’ group, and consideration of investors’ requirements.

VI. RISKS AND OPPORTUNITIES

The following list of risks and opportunities is proposed for the implementation of the «digital audit» system (see Table 2).

TABLE II. LIST OF RISKS AND OPPORTUNITIES FOR A DIGITAL AUDIT SYSTEM

Factor	Risk/Possibility	Impact	Consequences
Competent auditors	Availability of specialists skilled in audit and digital expertise on equal terms	Large	Failure to complete the audit program
Secure IT infrastructure	SLA target (deadline for submission of the audit report to senior management)	Large	Failure to perform corr. measures in due time
Management inaction	Completeness and promptness of corrective actions fulfillment, determined by the auditors	Critical	Failure to perform corr. actions in due time or complete
Cascade training	Possibility to implement on-site audits with the required frequency “on demand” (several entities at a start-up facility)	Medium	Failure to perform corr. actions in due time or complete

The presented list of risks and opportunities is the most efficient in terms of compliance with the requirements of international standards (e.g. ISO 9001 series or ISO/IEC 27001 series), business requirements in terms of the possibility of operational monitoring of key performance parameters of the group of construction companies by senior management and taking into account the requirements of audit standards (as illustrated above).

VII. FUNCTIONAL REQUIREMENTS FOR THE DIGITAL AUDIT SYSTEM

The following functional requirements for the “digital audit” system were determined at the design level:

- measurable - for the facility under audit “in the field” (manufacturing facility), measurable numerical assessments of compliance with the established criteria are provided, and a “digital footprint” is recorded (plan/fact for technical and human resources (THR), availability factor, output);
- transparent - the system provides transparent access of stakeholders to audit results with confidentiality measures (for investors, engineering companies, contractors);
- independent - internal and external auditors can cooperate in the system, providing independent assessment by various criteria (internal regulations, industry requirements, global and national standards);
- open - the system operates with data from current corporate IS (e.g. 1C:ISCUZ, 1C:CA, 1C:ZUP) for operational traceability in its internal closed and secure IT infrastructure.

VIII. CONCLUSIONS

The present publication suggests the results of operational testing a “digital audit” system for a group of companies, that is supported by unbiased data. The scientific novelty lies in the proposal of a closed-loop system of internal audits ensuring quick feedback and a unified comparable assessment for different stakeholders. The obtained results may be of interest to experts of certification bodies

performing management systems audit in line with the requirements of national and global standards.

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Ensuring Security at Facilities of Large Area Coverage

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Abstract—The present publication deals with the issue of ensuring security requirements at Fuel and Energy Sector facilities of large area coverage. The importance of this issue is explained by the need to improve the procedures for ensuring security requirements in up-to-date conditions on the basis of a new solution: portable electronic identifiers. An important factor is the reduction of financial costs for monitoring thousands of employees at the enterprises of large area coverage with a constantly changing perimeter.

The utilization of a cutting-edge IT solution capable of functioning in adverse conditions, including extreme temperatures, is proposed. It demonstrates that if the current procedure of “manual” monitoring or episodic control is kept, then it is impossible to ensure the necessary level of effective fulfillment of security requirements at distributed facilities. It is also shown that electronic identifiers can effectively monitor not only defined zones, but also “blind spots”, where employees may be out of visual control for a long time by means of video surveillance. These outcomes can be applied to ensure security requirements at Fuel and Energy Sector facilities of large area coverage.

Keywords—*industrial facility, production safety, requirements, electronic wristband, monitoring*

I. INTRODUCTION

The subject of the study, the results of which are presented in the publication, is the ensuring of manufacturing security requirements at industrial facilities of the Fuel and Energy Sector of large area coverage. The relevance of this issue is explained by the need to improve the procedures for ensuring the requirements of production security in the current conditions on the basis of new solutions, including portable digital trackers. Minimization of financial costs for monitoring of thousands of workers at facilities of large area coverage with a constantly changing perimeter is of a high importance.

The author’s propose the use of a modern IT solution capable of functioning in adverse conditions, including extreme temperatures. It is shown that if the current procedure of “manual” monitoring or episodic control is maintained, it is not possible to ensure the necessary level of actual fulfillment of production safety requirements at distributed facilities. The task of managing “near miss incidents”, which can be promptly detected, documented and investigated thanks to new IT solutions, is covered separately.

Examples of practical testing of portable electronic bracelets at several sites in 2023-2024 are presented. It is shown that digital trackers allow to effectively monitor not only specific zones (e.g., warehouse zones), but also dangerous intersection zones (e.g., where complex structures

are being assembled) or “blind spots” (e.g., when several units of equipment are working together), where some employees may be out of visual control by video surveillance means for a long time. The presented results can be applied to ensure production safety requirements at facilities of a large area coverage.

II. PRODUCTION SAFETY REQUIREMENTS

When performing work at industrial facilities of the Fuel and Energy Sector in accordance with the current legislation, it is necessary to comply with a significant number of requirements in the field of Industrial safety. We will restrict ourselves only to the main documents of PJSC Gazprom certification system in the field of industrial safety for the purposes of this publication: STO Gazprom 18000.1-001-2014. In particular, STO Gazprom 18000.1-001-2014 enforce the following main provisions:

- ensuring the client’s control over the quality of work, safe operation of buildings and structures at facilities of subsidiary companies (clause B.6.6.10);
- monitoring of safe operation and serviceability of technical devices at HPF, equipment, facilities, devices and proper use of the protective devices at the facilities of the branches, taking into account the HSE requirements (clause B.7.10.2);
- compliance with HSE requirements at production facilities (clause B.8.13.4);
- development of regulations on labor safety, industrial, gas and blowout safety, verification of the regulations implementation at the facilities (clause 8.23.4);
- informs the head of the structural division, workshop, service, site on a daily basis on the status of work conditions at the facility (clause B.10.18);
- informs the foreman (supervisor) on the status of work conditions at the facility, ... and on bringing to responsibility the persons violating HSE requirements (clause B.11.8).

It is of vital importance to note that fulfillment of all the requirements mentioned above for industrial facilities where thousands of employees operate in the “manual” mode, does not allow to ensure the specified level of fulfillment of Industrial Safety requirements. Periodic (annual, as a rule) inspection, does not fully cover the actual state of Industrial Safety requirements fulfillment at the «field» facilities to a certain extent. It is of key importance to take into account the following aspect - it is extremely important not only to declare Industrial Safety requirements and control the degree of their fulfillment, but also to be proactive - to deal with the so-called «near miss» situations. This term, in short, means

an incident that could have led to negative consequences (injuries), but thanks to the measures taken this did not happen.

Identifying, documenting and thoroughly investigating such near misses is critical because it allows for proactive identification of «indicators» of potential risks at a particular site. In addition, the requirement to investigate all types of Industrial Safety incidents is set out in the international standard ISO 45001:2018 Occupational health and safety management systems - Requirements with guidance for use. This should be taken into account that stringent Industrial Safety requirements must be met for all projects (irrespective of the clients' geographical location) to ensure the HSE, especially at facilities of a large area coverage

When implementing current “manual” monitoring mode, it is not always and not to the full extent possible to ensure compliance with the above requirements. Even the application of a number of IT solutions (video surveillance) will not always be able to “cover” all workplaces at facilities of large area coverage, and at linear sections (e.g., pipelines) are practically not applicable. Use of new solutions, such as wearable compact indicators (e.g., “smart helmets” or DT), can solve the challenge Industrial Safety provision. As stated in the works of foreign [1,2,3] and domestic [4,5,6] scientists, there are enough projects in where new solutions have shown acceptable results.

However, it should be taken into account that for a number of facilities a constant perimeter with a clearly monitored zone is initially provided, and for the Russian Railways solutions it is also possible to locate monitoring base stations along fixed railways. Definitely, industrial facilities of the Fuel and Energy Sector, especially linear sections of pipelines, have a constantly changing perimeter, without the possibility of providing permanent data transmission systems. Severe environment is needed to add to the scope of requirements, in particular, at the Kovytko gas condensate field the absolute minimum temperature reaches - 54 °C). A comprehensive solution characterized by a set of advantages (e.g., cost, compactness, significant temperature range, possibility of constant expansion of functional capabilities, integration with various accounting systems to ensure production security, etc.) is offered in terms of developed solutions, such as, for example, “smart helmets”.

III. A BRIEF DESCRIPTION OF THE SOLUTION USED

The project implementation envisaged the use of Digital Tracker (DT) Work Watch - “smart” wearable devices by ITS company to improve the efficiency of monitoring the work activity of a significant number of employees and specifically to ensure Industrial Safety directly at the Fuel and Energy Sector facilities of large area coverage.

The demonstrated DT works similar to standard trackers: a compact digital device equipped with an accelerometer and a gyroscope, which algorithms help to determine the level of physical activity of a particular employee. It is important for the purposes of this publication that an DT provides monitoring of movements with the ability to warn of hazardous areas, which is extremely important for ensuring the requirements of Industrial Safety at Fuel and Energy Sector facilities of large area coverage. There is an opportunity to send data on the absence of a pulse, falling down or pressing the SOS button to the remote panel of a responsible employee.

The Bluetooth beacon technology detects and records the activity of employees in certain areas, and the DT work both

indoors and outdoors. An important advantage of the DT is the following option - in case of a continuous idle time or when an employee is in a hazardous area, the DT offers to select the reason. Besides, DT allows to control not only recorded zones, but also dangerous intersection zones (for example, where pipelines are being installed) or “blind spots” (for example, when several large equipment units are operating together), when some employees may be out of visual monitoring by regular video surveillance means.

IV. FOCUSING THE DT PROJECT ON MONITORING NEAR MISS INCIDENTS

Let us review a few examples, the most critical from the point of view of ensuring a set level of HSE at facilities of large area coverage:

- An employee has accidentally (intentionally) moved away from a determined work area and is approaching a hazardous work area (an example is shown in Figure 1);



Fig. 1. An example of a dangerous employee moving.

- An employee approaches the area where Fuel storage Area or other tangible asset assets are stored, although according to his/her occupation (type of work) he/she should not be there;
- An employee approaches a “blind” spot (e.g. where several units of large equipment operate simultaneously, assembly, reloading of heavy equipment, etc.), where he/she may be out of visual control by regular video surveillance equipment.

It is worth repeating that continuous control by traditional “manual” methods, including on the basis of occasional formal inspections, does not provide objectively necessary results, especially for industrial facilities of large area coverage. Application of the new DT solution will allow to ensure prompt monitoring and prevention of Industrial Safety incidents at the facilities, and it is precisely the rapid preempting of all misses that will allow, minimally, to ensure:

- Effective risk analysis (identification and determination stage), without bringing the residual risks and closure of repeated Industrial Safety incidents to the treatment (according to the classical methodology of GOST R ISO 31000);
- Identify potential threats in a stress-free (non-rush) manner and predictively improve security measures (review residual risks), especially for facilities with a constantly changing perimeter;
- Improving security awareness- internal discussion of identified Industrial Safety incidents comfortably

affects the working environment, ensuring a true, rather than declarative, “security culture”;

- Documenting the fact of an Industrial Safety incident, especially in the absence of 24x7 technical opportunity for photo and video recording or in the absence of a supervising employee (manager). This data is a strong argument for the HR department comfortable mediation;
- Analysis of typical Industrial Safety incidents, e.g. frequency of hazardous area intersections (“but it's shorter that way, I didn't know there was a trench...”), above-normative deviations or violations of the in-situ (permit) control.

V. LIMITATIONS ON EXISTING INDUSTRIAL BP LEVEL CONTROL TECHNOLOGIES

In pilot projects, chrono metricians categorized some passive activities of employees as work, even though the employee was not physically active. For the purpose of verifying the correctness of the definition of workers' physical activity, we added to the data from the chrono metricians our own classification of operation types based on the determination, i.e. all permissible activities at sites where the employee is not physically active, for example:

- Lifting (lowering, moving) in the manlift;
- Receiving instructions on Industrial Safety fire works, etc.
- Assistance in equipment installation (e.g. diesel generator)

Another significant restriction is the “selective accuracy” in the reports provided by foremen for their teams. Traditionally, manual analysis of such reports is challenging and, for this reason, it is rarely followed up regularly. Accordingly, the pilot projects immediately revealed very significant discrepancies between the “manual” reports of foremen and the objective data obtained from the workers' DT for the same period.

One of the authors concluded from the pilot projects: “Foremen's reports cannot be used as a benchmark for determining the degree of activity of each worker or the team as a whole”. This judgment is based on numerous facts of comparison of foremen's reports and DT data, for example, the authors have an example when the output according to a paper report was more than 200%, while analyzing “digital data” of the DT- the output should not be more than 50%, idle time included.

Objectively, a pilot project in 2024 at a Northwest facility allowed data from over 76,000 man-shifts in DT to be analyzed, with an average of over 1,000 employees per day performing their functions with DT. The pilot project identified significant outcomes:

- Management (project managers) together with foremen personally have checked that the list of the “weakest” employees in terms of physical activity according to the DT data complies with personal data and the data received from foremen, moreover, it corresponds exactly to the identified Industrial Safety incidents;
- DT provides an unbiased basis for reasonable employee loyalty, including bonuses based on activity

ratings, and the absence of Industrial Safety violations;

- DT provides operational impact on the idle time of thousands of employees through daily analysis of physical activity reports with immediate identification of the causes of working time loss, including Industrial Safety incidents.

It's of vital importance for the purposes of this publication that while implementing a pilot project at one of Norilsk's facilities, several reports were analyzed within a certain period, and the results are given in Fig. 2.

Date	Master's report	Walking	Work time	Waiting	Down Time
01.08.2024	166%	8.4%	29.6%	47.0%	15.0%
02.08.2024	197%	10.2%	28.0%	45.7%	16.0%
03.08.2024	139%	8.8%	31.1%	46.5%	13.6%
04.08.2024	103%	9.1%	29.7%	47.2%	14.1%
05.08.2024	129%	8.7%	28.9%	44.1%	18.3%
06.08.2024	199%	10.6%	31.1%	47.2%	11.1%
07.08.2024	94%	11.6%	31.7%	47.5%	9.3%
08.08.2024	233%	10.8%	32.2%	45.4%	11.6%
09.08.2024	112%	11.9%	27.1%	47.6%	13.4%
10.08.2024	97%	9.7%	29.0%	45.7%	15.6%

Fig. 2. An example of a dangerous employee deviation

It is valuable that on the basis of unbiased data it was possible to determine further directions for optimizing the monitoring of employee activity identification (e.g., when 100% of output exceeds 100% according to “paper” reports of foremen).

VI. CONCLUSIONS

The implementation of the pilot projects discussed above allowed, unbiasedly, to identify new directions of DT usage for addressing the assigned task:

- DT record a worker's physical activity every second from the time the DT is received up to the moment it is returned, thereby providing the required “coverage” of monitoring of HSE requirements.
- DT allows to identify foremen, masters, supervisors, workers (“outsiders”), whose physical activity indicators for a long period of time are significantly below the average at the facility, thus allowing to take measures to prevent HSE accidents.
- DT allows to identify and utilize best practices, for example, to take as an impartial «benchmark» the best teams by the criterion of absence of working time losses and HSE accidents.

The advantage of the proposed solution is that it provides for the Industrial Safety at a higher level, in comparison with «manual» monitoring methods ensuring the HSE requirements performance at the facilities of Fuel and Energy Sector of large area coverage.

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Data Security Provision for Digital Transformation Processes

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Abstract—This publication considers the issue of providing security for digital transformation projects for companies undertaking various projects. It is known that there is a large gap between the expectations of the companies' top management for the effectiveness of new IT technologies compared to the allocated funds (including considerable budgets). Besides, there is a well-known challenge of IT security cost estimation, on quality of which depends the final result of digitalization. Definitely, the effectiveness of any digital technology is largely determined by the realization of IT security functions: data availability (accessibility) and data quality (reliability). It is suggested to consider the issue of reliable data generation not only in the aspect of specific IT solutions usage, but also in the aspect of IT security and specifically - ensuring the integrity and availability of data in the company's "digital conveyor belt". The obtained outcomes may be of interest to companies, operating EPC-projects for the benefit of large companies, as well as to experts in charge of proper risk management.

Keywords—digital transformation, project, construction company, function, mapping, standard, risks, OT solutions, metrics, oil and gas companies

I. INTRODUCTION

Currently, the pivotal point within the attention of stakeholders is the implementation of major infrastructure projects for the benefit of oil and gas companies. This focus of attention can be grounded on the need to monitor significant costs, the long-term projects (e.g., EPC), the length of linear facilities (pipelines) and the crucial importance for the Russian economy in general.

Project management and scope accounting methodologies which actually allow to assess the level of completion at a particular site by daily and monthly schedules (DMS). The problem with many methodologies is the inconsistency of classifiers (in particular, the names' normalization), in addition, there is objectively insufficient information on the exact metrics by which to judge on the success of particular projects.

There are studies on digital transformation of foreign [1,2,3] and Russian scientists [4,5,6], which describe the current status in the field of digital transformation in the sector of oil and gas industry in sufficient detail, but without addressing the specifics of the projects. As a rule, approaches to digital maturity, general directions of digital transformation of Fuel and Energy Sector (FES) enterprises, as well as some economic aspects of implementation are given. The studies present general data on digital transformation of energy sectors of various countries, cost-effectiveness assessments for digital technology initiatives, formal verification, employing of digital twins, and etc. Obviously, any expertise in such a cutting-edge area as

digital transformation is essential, but there are still no practical examples, methodologies and recommendations taking into account the specifics of Fuel and Energy Sector projects.

The presented publication proposes a new approach to evaluating quality (taking into account a number of parameters indicating deviations) of digital transformation processes of companies engaged in oil and gas projects in terms of the relevant data generation. Based on the author's experience in the realization of some projects, it is assumed that prioritizing attention to the availability and reliability of the necessary data will allow to form a "digital conveyor" and ensure the required quality of digital transformation of projects for the Fuel and Energy Sector facilities.

II. THE CONCEPT OF "DIGITAL TRANSFORMATION"

The concept of "digital economy" should not be considered absolutely new; it is known that this term was introduced in 1995 by Canadian scientist Don Tapscott, having described the digital objects representation, the impact of IT on business, public administration system, etc. In a certain respect, it is a variant of a new representation of economic objects of different nature. According to another version, this term was first introduced by the American IT specialist Nicholas Negroponte. Some publications note the relevance of the correct term for the projects of digital transformation of business of Russian Fuel and Energy Sector organizations. They also give their own interpretations of the term «digital economy» on the example of oil and gas companies.

Objectively, one may note that in terms of the system approach one can reasonably refer to a new (economic) mapping of well-known entities (processes, personnel, technical systems, etc.), or refer to a currently used mapping of a set of entities, enlarged with a new parameter, i.e. digital communications. For the purposes of this publication, let us determine a mathematical model:

$$F[(A), (X), (S), (G)] \rightarrow Y \quad (1)$$

where:

- A – algorithms that implement management functions (e.g., activity progress charts (APC), DMS, etc.);
- X – parameters characterizing the status of the management facility (e.g., remoteness);
- S – a system of restrictions (e.g., technical and human resources (THR), time, budget);
- G – management objectives (e.g., availability value as of a date);

- Y – management outcome (e.g., project commissioning on time).

The term “company’s digital transformation” is known as a “complex transformation of the company’s business model, products and services and/or business processes, aimed at enhancing the company’s competitiveness and achieving the company’s strategic goals and meeting the criterion of economic efficiency based on the implementation of a portfolio of initiatives for the introduction of digital technologies, use of data, development of human resources, competencies and culture for digital transformation, state-of-the-art methods for managing the implementation of digital solutions and financing the application of digital solutions”.

Herein it is of vital importance that the presented concept includes “achieving the company’s strategic goals”, i.e. it implies an objective judgement on measurable predetermined key indicators within the digital management system of a contemporary company. However, this term does not fully explain the differences between business processes digital transformation and business processes classical automation.

The oil and gas industry is one of the industries where emphasis is placed on digital transformation. “Digitalization of the oil and gas sector means the utilization of new high technologies within current business processes without altering their principles and structure”. Digital transformation involves improving and changing business processes by managing a set of digital technology elements, such as components (A) and (X) in (1). This assumption specifies employing of new entities (new IT solutions), i.e. the model (1) takes into account a new parameter, but does not assume a systematic “reprocessing” of existent business processes and their interconnections, therefore the achievement of the Y objectives is doubted.

Several optimization tasks can be proposed for the presented model (1), for example: which business process algorithms (A) should be modified for the most cost-effective solution under the given restrictions (S) in order to achieve the set goals (G)

It should be noted that a number of publications briefly discuss tasks of this type, although direct evidence of the progressive economic impact of new technologies (digital twins, big data, etc.) is obviously not provided. Accordingly, it is necessary to determine what will be different in each case in the basic model (1), or will the practice of digital transformation projects show what would be optimal to change: business processes or will it be more appropriate to introduce new IT solutions?

III. SETTING “DIGITAL TRANSFORMATION” GOALS FOR THE OIL AND GAS INDUSTRY

It is commonly known that there are certain trends of digital transformation in the oil and gas industry, i.e.: advanced analytics, Big Data, Industrial Internet of Things (IIoT), blockchain, cloud technologies, artificial intelligence, etc. The global leaders of digital transformation in the oil and gas sector are Shell, Chevron, BP (available data from reviews in 2008 - 2019). The leaders of digital transformation are Shell, Chevron, BP (data from 2008 - 2019 reviews are available) in the oil and gas sector as global practice shows. For example, such measurable indicators as CAPEX (capital expenditures estimation) are proposed - it is declared to decrease by 50% and oil recovery factor - declared to increase up to 10%. The following estimates are submitted for Russian companies (e.g., Rosneft):

- number of remotely controlled facilities - increase by a 60% is declared;
- energy efficiency of extraction processes - increase by 5% is declared;
- logistics costs – decrease by 5% is declared;
- economic effect - is expected to amount to about 1 bln. rub. per year.

IV. ANALYTICS ON THE LARGEST GLOBAL COMPANIES

It goes without saying, that for companies that act as contractors for the largest companies in the Fuel and Energy Sector, the requirements of digital transformation are essential. It is known that the “Top 10” largest companies in the world with revenues up to 42 bln USD (China Communications Construction Group Ltd) and up to 210 thousand employees (ACS Actividades De Construcción Y Servicios S.A.) have opportunities to “invest” in digital transformation initiatives, but the budget status in Russia and worldwide is different.

By the estimation of McKinsey consulting company (report “Accelerating growth in construction technology”) typical IT costs for companies in the AEG (Architecture, Engineering, Construction) sector are in the range of 1% to 2% of turnover (revenue) compared to the range of 3% to 5% in other areas. IDC estimates that IT costs (infrastructure and software) for companies are approximately 1.7% of turnover, compared to 5.3% for other domains.

KPMG reports that only 8% of companies have online accounting systems and dashboards, while about 15% use disparate electronic tables or manual processing (Figure 1). This example shows that only a limited number of the global companies proceed with digital transformation expertise, while the majority of companies still operate with rudimentary Excel sheet files.

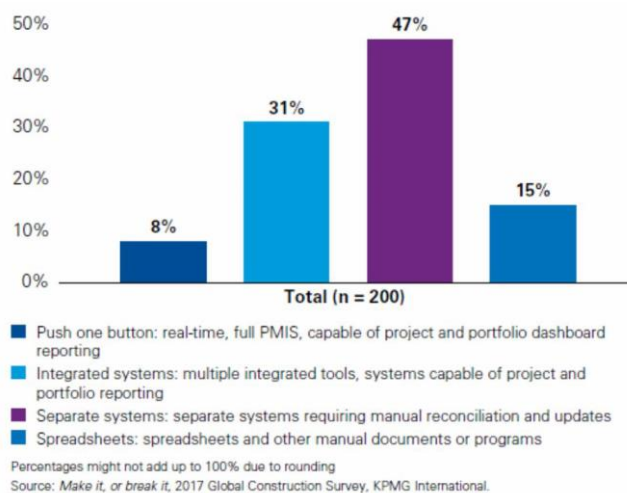


Fig. 1. Assessment of applied solutions for construction companies

“Heat map” (Figure 2) shows that the digitalization level for the construction industry upon a whole remains one of the lowest among all sectors (only agriculture’s level is lower). This example can be fairly considered a phenomenon, as an effective corporate governance tool is essential for the largest companies operating with billions of dollars and managing hundreds of thousands of employees globally.

The construction industry is among the least digitized.

McKinsey Global Institute industry digitization index; 2015 or latest available data

Relatively low digitization Relatively high digitization
● Digital leaders within relatively undigitized sectors



Fig. 2. The "heat map" of digitalization of various industries

It is advisable to briefly note the comparable security ratings, which allow us to analyze the suggested issue in an integrated - not separately from the "pure" IT framework but in combination with the critical functions of ensuring data availability and confidentiality in the "digital conveyor". The current report, "2024 Threat Detection Report," collects data from more than 1,000 customers of various sectors (including oil and gas companies) in a capacity of more than 216 Petabytes.

The percentage of identified threats per sector is summarized in Fig. 3, the sector (Construction) and oil & gas (Mining, quarrying, & oil & gas extraction) holds the middle area of the rating, which shows a favorable picture on its own, but when it is systematically compared to the low level of digitalization ratings (Fig. 2), quite alarming status of affairs is observed.

Detections per customer by industry

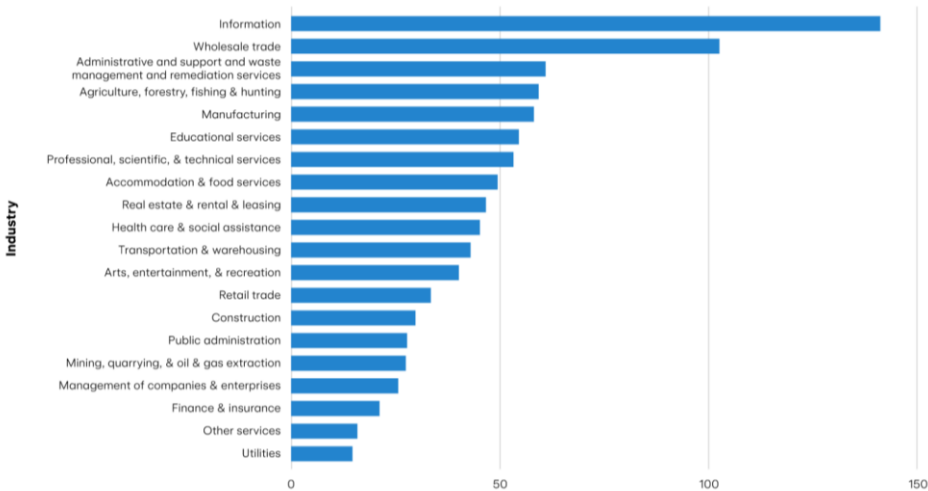


Fig. 3. Statistics of identified security threats by industry

V. THE FORMATION OF AN ASSESSMENT OF THE "DIGITAL TRANSFORMATION" RELIABILITY.

Given the current requirements for digital transformation, it seems reasonable to recommend the following indicators in

addition, which are designed to provide the "digital conveyor" reliable data in 3 main areas:

- Content (PBS - product breakdown structure), a component that describes the composition of the facility (items) and physical entities (equipment, etc.);
- Deadlines (WBS - work breakdown structure), a component describing the percentage of contract schedule fulfillment according to known project documents (work progress charts, daily and monthly schedules, work orders);
- Cost (CBS - cost breakdown structure), a component describing the decomposition of technical and human resources (THR) labor cost.

Given the facts presented above, let us address the content of the criteria that are expected to be included in the computation of the new component (R) compared to the baseline model (1):

$$F[(A), (X), (S), (G), (R)] \rightarrow Y \quad (2)$$

The following parameters are assumed to be included in the new component (R) characterizing the deviations in the new model (3):

- WBS/CBS (scope utilized);
- PBS/WBS (THR provision schedule);
- CBS/WBS (payment schedule);
- KPI deviation (personnel, control and measuring devices, readiness).

VI. CONCLUSIONS

This publication addresses the issue of implementing digital transformation projects for companies running all kinds of oil and gas projects. A proposed way of ensuring the reliability of «digital conveyor» data is to employ additional indicators that characterize deviations (in terms of the

utilized scope, THR schedules, and various KPIs). The results obtained may be of interest for companies, conducting EPC projects for the benefit of large oil and gas companies, as well as to experts in charge of project risk management.

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Control of Transactions in the Field of Combating Money Laundering and Terrorist Financing: Integrating Smart Contracts with Dynamic Risk Assessments

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Abstract — The article presents a methodology for developing a control system designed to automatically detect suspicious transactions and reduce operational risks associated with money laundering and terrorist financing in the context of the development of digital financial assets.

The methodology is based on the integration of smart contracts executed on the blockchain with a dynamic risk assessment system using current data from national and international assessments received through Oracle networks. The implemented prototype demonstrates an increase in accuracy (Precision) by 5%, completeness (Recall) by 10% and a decrease in the level of false positives by 15% compared to traditional rule-based systems.

Keywords – *blockchain, smart contract implementation, Oracle networks, dynamic risk assessment system, transaction monitoring, decentralized finance*

I. INTRODUCTION

In the current conditions of globalization and digitalization of the economy, the issue of countering money laundering obtained through criminal means and the financing of terrorism (CML/TF) is becoming particularly significant. According to the Financial Action Task Force (FATF), many countries face insufficient effectiveness in implementing FATF recommendations to combat money laundering and terrorism financing (CML/TF), which creates vulnerabilities in control mechanisms [1]. The problem becomes particularly acute in the context of digitalization of the financial system, where the volume of transactions is growing exponentially, and the use of new technologies such as cryptocurrencies and smart contracts creates additional vulnerabilities. For example, the volume of illegal operations involving cryptocurrencies in 2023 reached \$23.8 billion, which is 15% higher than the previous year's figure [2]. In Russia, according to the National Risk Assessment of Terrorism Financing, the key issues are: a high level of risk when attracting funds through social networks, messaging apps, and crowdfunding platforms [3]; moving cash through

unregulated payment systems without opening a bank account [3]; problems with identifying electronic wallets and monitoring operations involving virtual assets [3]. A particular concern is the increasing number of complex schemes for financing terrorist activities, including the use of legal income sources from non-profit organizations and legal entities [3]. Modern trends in information technology contribute to the transformation of methods of terrorism financing. At the same time, attracting funds via the Internet for terrorism financing is becoming an increasingly common practice, posing a serious threat to financial security. This underscores the need to implement modern technologies to automate transaction monitoring processes and improve their transparency.

In the context of growing data volumes and increasing complexity of financial transaction schemes, modern anti-money laundering (AML) and counter-terrorism financing (CTF) systems based on manual analysis or statistical rules are unable to respond promptly to new criminal behavior patterns. They face several significant limitations that reduce their effectiveness. One of the key issues is the high level of false positives associated with the application of rigid rule-based systems, which leads to substantial costs for both financial institutions and regulators. According to FATF, traditional control systems demonstrate up to 30% false-positive results, due to their inability to consider the context of operations and dynamically adapt to new threats [4].

A major limitation of traditional systems is their inability to account for regional features and the specifics of various client categories. Modern analysis methods often ignore differences between individuals and legal entities, as well as factors such as geography of transactions, transaction frequency, and the reputation of participants [5]. This results in systems that are either insufficiently sensitive to real threats or overly conservative, blocking legitimate transactions.

This situation emphasizes the need for the development of an innovative (new) approach that combines transaction monitoring automation using smart contracts, taking into account dynamic risk criteria. Such an approach should be based on the use of current data from national and international risk assessments, as well as technologies that minimize the human factor and enable rapid response to changes in the behavior of market participants. Solving this problem will not only reduce false positives but also enhance the overall effectiveness of AML/CTF systems, ensuring their alignment with modern challenges.

II. OVERVIEW OF THE CURRENT SITUATION IN THE SUBJECT AREA

Counteracting money laundering (ML) and terrorism financing (TF) is one of the key tasks of modern financial systems. The issues of the impact of illegal capital movement on a country's economic development have been studied by both foreign researchers (G. Ardizzi, G. Becker, P. Gutmann, V. Unger, D. Walker, and others) and Russian scholars (S.P. Ilyukhin, V.G. Kleiner, V.V. Kulikov, Yu.V. Latos). The problem of the interconnection and interdependence of individual stages of money laundering is considered by the International Monetary Fund (IMF), the World Bank, and the Financial Action Task Force (FATF).

The analysis of national AML/CFT systems of foreign countries is presented in the works of A.V. Ilyin [6], I.V. Nikitenko, E.A. Isachenko [7], V.G. Morozov [8], L.P. Korolyova, U.I. Yevseeva, E.V. Bezrukov [9], A.K. Gismatulina [10].

IMEMO RAS is engaged in research into modern trends in the restructuring of the global financial system under the influence of technological, economic and political factors associated with the development of financial and regulatory technologies, and the problems of their impact on the mechanisms of money laundering and terrorist financing within the framework of the Comprehensive Scientific Research Program "Mathematical and Socio-Economic Modeling for the Purpose of Combating Money Laundering and Terrorist Financing". Within the framework of this program, additional research is being conducted on the following topic: "Technological, Socio-Economic and Geopolitical Drivers of the Development of Crypto-Asset Ecosystems in the Global Economy: Challenges for Countries and Regulators in the Sphere of AML/CFT".

A brief overview of the current state of the studied problem indicates that there are no comprehensive studies dedicated to the pressing issues arising in the context of digitalization, specifically the integration of smart contracts with dynamic risk assessments for transaction monitoring in the field of AML/CFT.

III. FORMULATION OF THE TASK AND THE METHOD OF ITS SOLUTION

Special attention in the development of measures to combat money laundering is given to the assessment of the risks of money laundering and terrorist financing. According to the National Risk Assessment of Terrorist Financing of the Russian Federation, the process of threat identification includes three main stages: the attraction of funds, their transfer, and their use. [11]. Each of these stages is characterized by certain vulnerabilities (geographical factor: high-risk jurisdictions; transaction amounts: exceeding threshold values; frequency of operations: multiple

transactions within a short period), which can be exploited for illegal activities.

Currently, traditional transaction monitoring systems are used to analyze suspicious activities. These systems are based on rule-based approaches, where strict rules are employed to identify suspicious transactions. These systems have the following disadvantages: a high false-positive rate (up to 30%) [12]; manual analysis of large volumes of data [5]; inability to adapt to new patterns of behaviour of market participants [13].

Solving these problems in the context of digitalization is possible based on the integration of smart contracts, which are autonomous programs operating on the blockchain and executing pre-defined conditions without the participation of third parties [14], combined with dynamic risk assessment.

For transaction monitoring in the field of AML/CFT, this approach will allow:

- minimize the human factor;
- ensure transparency and immutability of data;
- automatically respond to changes in market participants' behavior.

IV. TECHNICAL ARCHITECTURE OF THE IMPLEMENTATION

For the technical implementation of the proposed solution, the following architecture is proposed:

Smart contract layer:

- Implementation language: Solidity 0.8.x using OpenZeppelin libraries to protect against known vulnerabilities
- Example of a smart contract structure

```
// SPDX-License-Identifier: MIT
//Main structure for storing transaction data {
    address sender;
    address receiver;
    uint256 amount;
    string country;
    uint256 frequency;
    bool isSanctioned;
    uint256 riskIndex;
    bool isBlocked;
    uint256 timestamp;
}
//Function calculate Risk Index (
    uint256 amount,
    string memory country,
    uint256 frequency,
    bool isSanctioned
) internal pure returns (uint256) {
    //Normalization of values
    uint256 amountFactor = amount > 100000 ? 150 : 100; // 1.5 uuu 1.0
    uint256 geographyFactor = getCountryRisk(country);
    uint256 frequencyFactor = frequency > 5 ? 120 : 100; // 1.2 uuu 1.0
    uint256 reputationFactor = isSanctioned ? 50 : 10; // 0.5 uuu 0.1
    //Calculation of RI
    //Function check Transaction (
        address sender,
        address receiver,
```

```

uint256 amount,
string memory country,
uint256 frequency,
bool isSanctioned
) public returns (bool) {
    uint256 ri = calculateRiskIndex(amount, country,
frequency, isSanctioned);
    bool isBlocked = ri > 150; // 1.5 в сотых долях
    transactions[transactionCounter] = Transaction(
sender, receiver, amount, country, frequency,
isSanctioned, ri, isBlocked, block.timestamp
);
    transactionCounter++;
    return isBlocked;
}

```

The following formula is used for quantitative risk assessment, known as the Risk Index (RI):

$$RI = W_1 \times \frac{\sum T}{\sum T} + W_2 \times GF + W_3 \times Fr + W_4 \times Re \quad (1)$$

where

$\sum T$ – total amount of transactions;

$\sum T$ – medium amount of transactions;

GF – geography factor;

Fr – frequency;

Re – reputation;

$W_1=0.4$ – weighting factor for transaction amount [13];

$W_2=0.3$ – weighting factor for geography factor [12]

$W_3=0.2$ – weighting factor for frequency of operations [5].

$W_4=0.1$ – weighting factor for reputation [2]

All the weights of the RI coefficients correspond to the priorities outlined in the FATF reports and the methodology of the National Risk Assessment of the Russian Federation (Table 1).

TABLE. I. WEIGHTS AND THEIR SOURCES

Factor	Weight	Rationale (source)
Amount	0.4	FATF: threshold amounts are a key risk indicator (стр. 50).
Geography	0.3	National assessment of the Russian Federation: high-risk jurisdictions (стр. 13).
Frequency	0.2	FATF: "smurfing" schemes (section on cryptocurrencies).
Reputation	0.1	Chainalysis: 8% of illegal transactions are associated with sanctioned addresses.

Considering formula (1), the data presented in Table 1, and the information provided in the country risk assessment reports, we will calculate the RI (Table 2).

TABLE. II. RISK INDEX (RI) CALCULATION

Parameter	Value	Factor	Weight	Contribution to RI
Amount	\$150,000	1.5	0.4	0.6
Geography	Syria	2.0	0.3	0.6
Frequency	6 transactions/day	1.2	0.2	0.24
Reputation	Sanctions list	0.5	0.1	0.05
Final RI				1.49

If the risk index exceeds the value of 1.5, the transaction is blocked.

To create a transaction monitoring system, we use the Oracle system. The use of this system is justified by its ability to access up-to-date sanction lists (e.g., OFAC); update average transaction values based on Chainalysis data; respond to changes in legislation or international standards [12]. This will enable dynamic data updates.

Figure 1 shows the architecture of the transaction monitoring system.

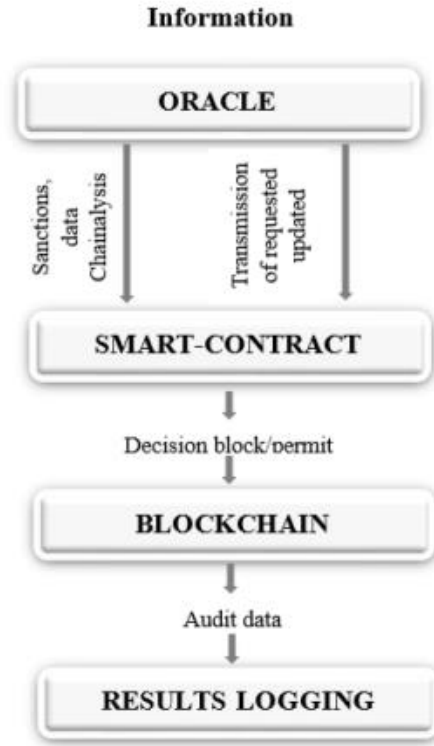


Fig. 1. Transaction control system architecture

V. TECHNICAL SECURITY OF THE SYSTEM

The following security aspects were taken into account during the system design process:

1. Smart contract protection:

- Using OpenZeppelin libraries to protect against known vulnerabilities
- Implementation of the Checks-Effects-Interactions pattern in critical functions
- Implementation of restrictions on the volume of data processed per transaction
- Checking for overflow in arithmetic operations (built into Solidity 0.8.x)

2. Data security:

- A quorum mechanism is provided to protect against data manipulation when updating data via Oracle
- Implemented caching of critical data with periodic updates
- Implemented data integrity checks before using them in calculations

3. Security testing:

- It is planned to conduct static code analysis using Slither Checking for vulnerabilities to reentrancy, front-running and gas griefing attacks
- Testing Oracle failure scenarios and processing incorrect data

The proposed prototype solves these problems by using up-to-date data and automating processes.

VI. EXPERIMENTS

To test the effectiveness of the proposed smart contract prototype, a technical simulation was developed and implemented using the following components:

A. Technical implementation of the simulation

The simulation was implemented in Python 3.10 using the following libraries and tools:

- data generation: Faker library for creating realistic test data;
- smart contract modeling: Implementation of smart contract logic in Python (analogous to Solidity code);
- oracle simulation: Mock objects for simulating receiving data from external sources;
- analysis tools: Pandas and NumPy libraries for processing results;
- visualization: Matplotlib and Seaborn for plotting.

The technical implementation of the simulation included

1. Data generation:

- creation of a sample of 500 transactions (200 illegal and 300 legal) based on official statistics presented in the Chainalysis report [2];
- illegal transactions included HYIP schemes, pig butchering scams and transfers to sanctioned addresses;
- legal transactions corresponded to standard financial transactions (payment for services, transfers between accounts);
- transaction parameters were generated taking into account statistical data from the Chainalysis Crypto Crime Report [2].

2. Simulation of Oraclert operation:

- implemented a mock object simulating the receipt of data on sanctions lists;
- implemented a mock object for obtaining average transaction values;
- implemented a mock object for obtaining data on high-risk jurisdictions;
- example of mock object implementation

class MockOracle:

```
def __init__(self):
    self.sanctions_list = ["0xSanctionedAddress1",
"0xSanctionedAddress2"]
    self.average_transaction_amount = 85000
    self.high_risk_countries = ["SY", "IR", "KP", "CU"]
def is_sanctioned(self, address):
    return address in self.sanctions_list
def get_country_risk(self, country):
    return 2.0 if country in self.high_risk_countries else
```

1.0

3. Technical characteristics of the simulation:

- average processing time for one transaction: 1.8 seconds;
- processing time for 500 transactions: 15.2 minutes
- time distribution:
 - seconds - Risk Index calculation
 - seconds - Oracle response simulation
- resource consumption: 120 MB RAM, 15% CPU

B. Testing methodology

The following metrics were used to evaluate the system efficiency:

- Precision: share of correctly blocked transactions among all blocked ones;
- Recall: share of correctly blocked transactions among all illegal transactions;
- F1-measure: harmonic mean between Precision and Recall;
- False Positive Rate.

For each transaction, the Risk Index (RI) was calculated using formula (1). The calculation results are presented in tab.3.

TABLE. III. RISK INDEX CALCULATION

№	Amount (\$)	Country	Frequency	Risk	RI	Solution
1	150.000	Syria	6	Sanction	1.49	Blocking
2	50.000	Germany	1	High	0.61	Permiss
..			...	...	..	ion
500	75.000	Russia	2	Medium	0.85	Permission

Justification for the choice of the RI threshold value = 1.5. The RI threshold of 1.5 was determined empirically based on the analysis of the risk index distribution, calculated on a test sample of 500 transactions (300 legal and 200 illegal). The histogram (Figure 2) of the RI distribution clearly shows that at $RI \approx 1.5$, the left part (legal transfers) and the right part (illegal transfers) practically do not overlap, ensuring an optimal balance between recall (92%) and precision (88%) at a false positive rate of approximately 15%.

The value of 1.5 also coincides with the "average threshold," which is the ratio between the volume of a large transaction (150,000 rubles) and the regulatory threshold (100,000 rubles), established in the National Risk Assessment of the Russian Federation for assigning a "moderately high" risk level. Thus, choosing $RI = 1.5$ is not arbitrary; it results from statistical analysis of the risk index distribution and aligns with practical recommendations from FATF and Rosfinmonitoring for minimizing false positives and false negatives.

V. RESEARCH RESULTS

Visualization of simulation results

In order to present the results, the following graphs were constructed, namely:

1. Distribution of RI (fig.2)

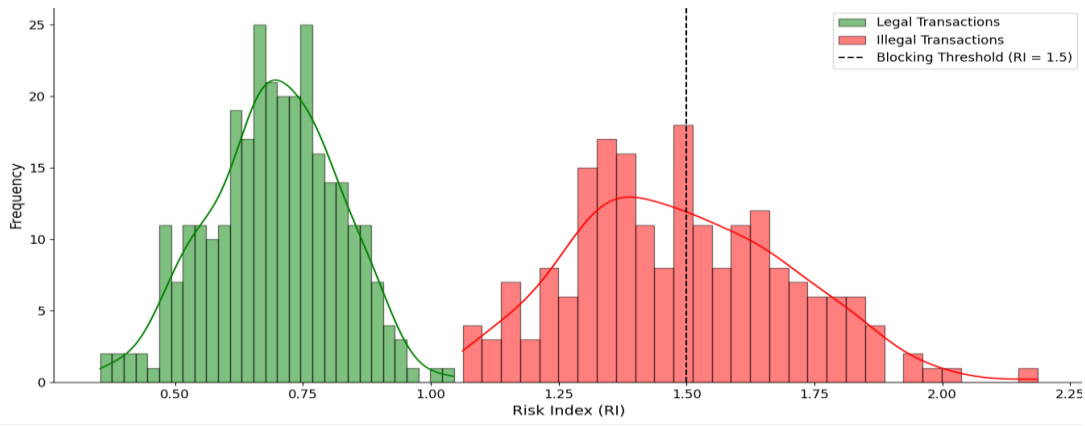


Fig. 2. Distribution schedule RI

Figure 2 shows the distribution of RI for legal and illegal transactions. The RI=1.5 boundary clearly separates most legal transactions from illegal ones.

1. Metrics comparison chart

During the operation of the proposed prototype, the following results were obtained:

- 180 illegal transactions were correctly blocked (TP=180);
- 20 illegal transactions were not blocked (FN=20);
- 255 legal transactions are correctly allowed (TN=255);
- 45 medical operations were erroneously blocked (FP=45).

For graphical representation it is necessary to calculate the following indicators:

1.1. Precision

$$\text{Precision} = \frac{TP}{TP + FP} = \frac{180}{180 + 45} = 0.8 \text{ or } 80 \% \quad (2)$$

2.2. Recall

$$\text{Recall} = \frac{TP}{TP + FN} = \frac{180}{180 + 20} = 0.9 \text{ or } 90 \% \quad (3)$$

2.3. F1-measure

$$F1 = 2 \times \frac{\text{Precision} \times \text{Recall}}{\text{Precision} + \text{Recall}} = 2 \times \frac{0.72}{1.7} \approx 0.847 \text{ or } 84.7 \% \quad (4)$$

2.4. False Positive Rate, FPR

$$FRR = \frac{FP}{TN + FP} = \frac{45}{255 + 45} = 0.15 \text{ or } 15 \% \quad (5)$$

Fig. 3 shows a comparison of metrics.

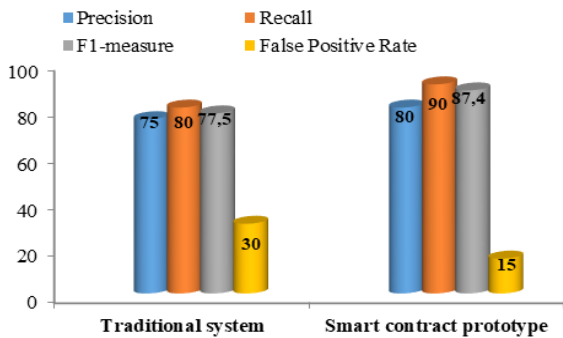


Fig. 3. Comparison of metrics of a traditional system and a smart contract prototype

Analysis of the data presented in fig.3 allowed us to conclude that the smart contract prototype outperforms traditional systems in all metrics.

The results of testing the prototype are presented in tab.4.

TABLE IV. SMART CONTRACT PROTOTYPE TESTING RESULTS

Parameter	Description	Traditional system	Smart contract prototype	Improvement (%)
Precision	The proportion of correctly identified positive cases among all those classified as positive	75%	80%	+5%
Recall	Share of correctly identified positive cases among all actually positive cases	80%	90%	+10%
F1-measure	Harmonic mean between precision and recall	77,5%	84,7	+7,2%
False positives	Percentage of cases where the system incorrectly classified a negative case as positive	30%	15%	-15%

According to the data presented in tab.4, the use of the smart contract prototype allowed to increase the following indicators:

Precision – the increase was 5%, indicating better filtering of illegal transactions;

1. Recall increased by 10%, which indicates that the system is successfully detecting a large proportion of suspicious transactions;

2. F1-measure (harmonic mean between Precision and Recall) increased by 7.2%, confirming the overall improvement in system performance.

3. The use of the smart contract prototype helped reduce the false positive rate from 30% to 15%. This is achieved through a combination of two key factors: dynamic consideration of risk criteria (such as transaction amount, geographic factor, operation frequency, and participant reputation [11]. and integration of up-to-date data via Oracle. This aligns with FATF recommendations on implementing risk-based approaches. [4].

However, despite the positive results, it is important to note the limitations encountered during the study, namely:

- *Lack of data on private transactions.* Private cryptocurrencies (e.g., Monero) are not considered

[2]. This limits the system's applicability for analyzing operations that use anonymity.

- *Limited sample size.* Using only Chainalysis data may not fully reflect real conditions. For example, the data might be biased towards large crypto platforms, ignoring decentralized finance (DeFi).
- *Dependence on the quality of input data:* The accuracy of risk predictions depends on the relevance and reliability of the data received through Oracle [5].
- *Fixed weight coefficients:* The RI weights are fixed to maintain the simplicity of the model. In future research, they can be adapted through regression analysis, but the current values strictly adhere to FATF recommendations and Russian regulatory practice.

VI. CONCLUSIONS

The implementation of a smart contract prototype with dynamic RI in the AML/CFT sphere will enable adaptation to the rapidly changing conditions of financial markets and serve as an important vector for creating a reliable and adaptive financial monitoring system that aligns with international standards. It also allows for reducing operational costs and increasing transparency of control processes. All decisions are recorded on the blockchain, which simplifies auditing and enhances trust in the system.

It is important to note that deploying such systems is associated with several limitations. First and foremost, the lack of data on private transactions, such as Monero or Zcash, which remain outside the scope of current analysis technologies. Additionally, dependence on the quality of input data and the complexity of integration with existing financial systems require further research and development. From a legal perspective, it should be considered that the use of smart contracts in AML/CFT is not yet clearly regulated, which creates additional risks for their practical application. The proposed prototype represents a significant step forward in transaction monitoring automation. It combines current data from national and international risk assessments with blockchain technology, which helps minimize false positives and improve the overall efficiency of the system. However, for full implementation and scaling, a number of technical and legal issues need to be addressed, opening new horizons for future research and development.

Ultimately, the success of combating money laundering and terrorist financing depends not only on technology but also on the ability of financial institutions, regulators, and the scientific community to work together to create a safer and more transparent financial system.

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Section 3 - Information Technologies

- **Strategies and Digital Transformation of Business and Industry**
- **IT in Industry, Medicine, Education**

Digital Transformation and the Use of Information Technology in Crisis Management

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Abstract — In the context of economic instability, digital transformation is positioned as a tool for anti-crisis management. However, the lack of quantitative assessments of its real effect leads to inflated expectations and suboptimal allocation of resources.

The study presents an original methodology for a comparative analysis of the baseline scenario of digital transformation and an extended scenario with the implementation of AI/ML solutions. Based on simulation modeling of a 75-month period covering the pre-crisis phase, acute crisis and subsequent digital transformation, it was found that the full implementation of digital capabilities allows businesses to restore up to 80% of the pre-crisis level of profit, while the baseline scenario provides recovery by only two-thirds. Particular attention is paid to the quantitative assessment of the contribution of AI/ML analytics, which, despite its relatively modest share in the overall effect of digitalization, demonstrates a statistically significant improvement in indicators. The analysis also revealed that the reduction in costs during the recovery period reaches 15% compared to the crisis period.

The obtained results allow us to confirm the role of digital transformation as a tool for managing the recovery of business indicators in the context of continuing unfavorable macroeconomic conditions. The study contributes to the theory of anti-crisis management by offering a substantiated approach to the allocation of resources in digital transformation, free from marketing exaggerations and based on quantitative assessments.

Keywords—digital transformation, crisis management, simulation modeling, ERP systems, machine learning, predictive analytics, cloud technologies, business resilience, macroeconomic analysis, digital maturity

I. INTRODUCTION

The modern economic environment is characterized by a high degree of uncertainty and a constant change of crisis phenomena, which requires a fundamental revision of traditional approaches to business management. Geopolitical changes, sanctions pressure and macroeconomic instability create conditions in which traditional methods of anti-crisis

management demonstrate limited effectiveness. In this context, digital transformation appears as a potentially powerful tool capable of ensuring business sustainability in the face of systemic crises.

The relevance of the study is due to empirical data on a significant drop in the financial performance of Russian companies in 2022-2023, which indicates the ineffectiveness of existing management methods in the new conditions.

The purpose of the study is to develop a quantitative model for assessing the effect of digital transformation on business sustainability in a systemic crisis, taking into account the contribution of various technological components. To achieve this goal, the following tasks are solved:

1. Analysis of existing approaches to digital transformation in a crisis and identification of gaps in the scientific literature
2. Development of a simulation model that takes into account the influence of macroeconomic factors and the specifics of the implementation of various IT solutions
3. Comparison of the effects of basic digital transformation and an extended scenario with the introduction of AI / ML and cloud technologies
4. Determination of time lags between the implementation of technologies and obtaining a positive effect
5. Formation of recommendations for the optimal allocation of resources during digital transformation in a crisis.

The methodological novelty of the study lies in a combined approach that combines simulation modeling with an analysis of the importance of factors based on machine learning. Unlike existing works, the proposed model takes into account the nonlinear influence of macroeconomic factors through a combined macro index and allows us to assess the contribution of specific technologies to the overall effect of digital transformation.

The practical significance of the study is to provide an objective quantitative assessment of the effect of digital transformation, which will allow businesses to form realistic expectations from the implementation of digital technologies and optimally allocate resources between the various components of digital transformation. The theoretical value of the work lies in the development of a conceptual model demonstrating the relationship between crisis management and digital transformation using specific IT solutions, which solves the gap in existing research.

II. REVIEW OF THE STATE OF AFFAIRS IN THE SUBJECT AREA

Recognition of the potential of digital transformation as a powerful tool for crisis management underscores the need to study this issue.

In both Russian and international literature, numerous studies are dedicated to specific aspects of digitalization and crisis management. It is important to note that there are no comprehensive studies that holistically examine the relationship between digital transformation and crisis management, as well as their impact on the overall resilience of business and production during crises.

Research into the interpretation of the essence and content of the concepts "digital business transformation" and "digital economy" has been conducted by P.D. Gorshechnikova, A.S. Dubgorn, I.M. Zaitchenko, and A.I. Levina, who proposed the following definition: "Digital business transformation is the transition from a traditional enterprise management system to an innovative one based on the implementation of relevant information and communication technologies into the enterprise's activities, aimed at transforming the business and/or its digitalization to obtain and/or maintain competitive advantages in modern society." [1].

Thus, Kochetkov E.P., Zabavina A.A., and Gafarov M.G. note that businesses and governments cannot achieve success without digital transformation; they can only do so by merely adjusting traditional management methods and models. [2]. Digital transformation of the economy requires a reorganization of all socio-economic institutions, including economic science and management, as well as the development of new crisis management tools. [2]. Yuditsev M.A. and Zaitsev A.G. emphasize the need to reconsider traditional crisis management methods in the context of the digital economy [3]. The issues of the effectiveness of choosing digital tools for crisis management depending on the type of crisis, industry and company resources were reflected in the studies of Tugce Nuray Saka, Esther Hormiga Pérez, Jaume Valls-Pasola [4].

Shabaltina L.V. and Maslennikov V.V. pay special attention to the need to use artificial intelligence to improve management efficiency [5].

The analysis of digital transformation of enterprises through the use of this tool and digital technologies in the crisis management system is considered by Ulbasheva F.D. and Podolskaya T.V. [6].

Issues of the impact of digitalization on the effectiveness of crisis management using both qualitative and quantitative methods of analysis were reflected in the studies conducted by Tubalets A.A. Korobkin A.A. Markaryan E.R., Ivakhno V.V. [7].

While positively evaluating the results obtained by Russian and international economists on digital transformation and crisis management, it is necessary to note the lack of independent theoretical, methodological, and practical provisions for developing a conceptual model that demonstrates the relationship between crisis management and digital transformation, taking into account the use of specific IT solutions.

III. STATEMENT OF THE PROBLEM AND THE METHOD OF ITS SOLUTION

Digital transformation, being an effective tool for crisis management, has a number of limitations and may be ineffective in cases of incompetent management. Digitalization has a complex and ambiguous impact on crisis management. On one hand, it provides companies with new opportunities to enhance resilience and adaptability through the implementation of specific IT solutions. On the other hand, digital transformation does not always yield the expected results.

In a crisis, traditional management systems face critical problems in data processing and decision-making. Analysis shows that 68% of companies experience delays in crisis decision-making due to ineffective data processing [7]. To address these issues, a conceptual model of digital transformation for crisis management is proposed, which includes five stages: identifying crisis factors, pre-crisis preparation, digital transformation, a set of measures to overcome the crisis, and business resilience.

A. Conceptual model of digital transformation

The proposed conceptual model (fig.1), is based on the integration of digital technologies into the crisis management process and includes the following stages:

1. **Identification of crisis factors.** At this stage, crisis factors emerge, which can be both external (technological shifts, economic downturns, geopolitical conflicts) and internal (ineffective management, financial instability, organizational problems).
2. **Pre-crisis preparation.** At this stage, the company carries out a series of preparatory activities:
 - **risk diagnosis.** Identification and assessment of potential risks are conducted using BI (Business Intelligence) systems for big data analysis;
 - **development of response plans.** Response plans are created based on data and analytics obtained through artificial intelligence (AI) and machine learning (ML) technologies;
 - **staff development.** Employees are trained in digital skills using remote learning platforms;
 - **creation of IT infrastructure.** A flexible and scalable IT infrastructure is established using cloud technologies.
3. **Digital transformation.** At this stage, specific IT solutions are implemented:
 - **process automation:** ERP systems (Enterprise Resource Planning), CRM systems (Customer Relationship Management), and MES systems (Manufacturing Execution Systems) are implemented to automate routine operations and enhance resource management efficiency;
 - **data analysis:** BI, AI, and ML systems are introduced for big data analysis and more informed management decisions;

- **flexibility and adaptability:** cloud technologies are used to ensure flexibility and scalability of the IT infrastructure, as well as mobile technologies to facilitate remote work;
- **communications:** video conferencing systems and corporate networks are implemented to enhance interaction between employees, partners, and clients

4. A set of measures to overcome the crisis. Based on data and analytics, measures are implemented to optimize internal processes, manage resources, and diversify sales channels.

5. Business sustainability. As a result, the company increases its sustainability and adaptability to changing external conditions. corporate social networks, which facilitate the rapid exchange of information, knowledge, and experience among employees.

Figure 1 presents a conceptual model of the relationship between crisis management and digital transformation, taking into account the use of specific IT solutions

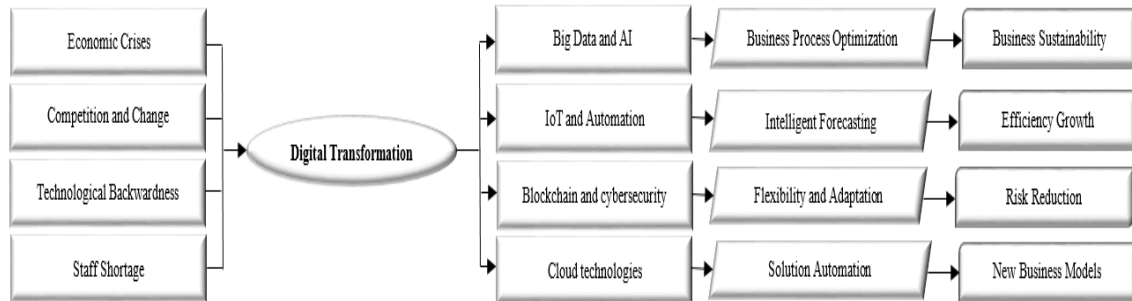


Fig. 1. Conceptual model of the relationship between crisis management and digital transformation

B. Proposed architecture for practical implementation of the conceptual model

The following architectural solutions are proposed for practical implementation of the research results:

1. Single data space:

For the integration of heterogeneous systems (ERP, CRM, MES), an API-first architecture using Apache Kafka is proposed. The streaming data processing configuration includes three main streams: `erp_stream` for integration with ERP systems via a JDBC connection, `crm_stream` for integration with CRM systems via MongoDB, and `mes_stream` for integration with production systems via the OPC UA protocol. This configuration provides a throughput of up to 100,000 messages per second with a processing latency of less than 100 ms, which is critical for prompt decision-making in crisis situations. Example of Kafka

Connect configuration for integration with ERP system:

```

name: erp-kafka-connector
connector.class: io.confluent.connect.jdbc.JdbcSourceConnector
tasks.max: 3
connection.url: jdbc:mysql://erp-db:3306/erp_data
mode: timestamp
timestamp.column.name: last_modified
topic.prefix: erp_
poll.interval.ms: 5000

```

2. Real-time processing system:

Stream data processing using Apache Flink is recommended for crisis scenario detection. The algorithm for detecting anomalies in financial transactions includes filtering transactions that exceed a critical threshold, grouping by account ID, using window functions to analyze time patterns, and generating crisis alerts.

Example of financial transaction processing code:

```

// Detecting anomalies in financial transactions
DataStream<FinancialTransaction> transactions = env
    .addSource(new FlinkKafkaConsumer<("erp_operations",
        new TransactionDeserializationSchema(), properties))
    .filter(t -> t.getAmount() > CRITICAL_THRESHOLD);
// Detecting abnormal patterns

```

transactions

```

    .keyBy(Transaction::getAccountId)
    .window(TumblingEventTimeWindows.of(Time.minutes(5)))
    .process(new AnomalyDetector())
    .addSink(new CrisisAlertSink());

```

3. Predictive analytics:

Integration of ML models via TensorFlow Serving has been implemented to predict crisis scenarios. The implementation process includes training the model on historical data, exporting the model to TensorFlow SavedModel format, deploying the model via TensorFlow Serving, and integrating with stream processing via the gRPC API.

Example of a request to the forecasting model:

```

# Forecasting a crisis scenario
def predict_crisis(features):
    request = predict_pb2.PredictRequest()
    request.model_spec.name = 'crisis_forecaster'
    request.inputs['features'].CopyFrom(
        tf.make_tensor_proto(features, shape=[1, len(features)]))
    result = stub.Predict(request, 5.0) # 5 секунд таймаут
    return result.outputs['predictions'].float_val[0]

```

4. Monitoring system:

To assess the effectiveness of digital transformation, a monitoring system based on Prometheus and Grafana was implemented. Key metrics include the accuracy of crisis scenario forecasting (`crisis_prediction_accuracy`), data processing latency (`data_processing_latency`), system availability (`system_availability`), and alert response time (`alert_response_time`).

Example of metrics:

```

# HELP crisis_prediction_accuracy Точность прогнозирования
# TYPE crisis_prediction_accuracy gauge
crisis_prediction_accuracy{model="lstm"} 0.87
crisis_prediction_accuracy{model="prophet"} 0.82

```

IV. EXPERIMENTS

To test the hypothesis about the impact of digital transformation on business sustainability in a crisis, we

developed and implemented a comprehensive simulation experiment. Unlike existing approaches, our model takes into account not only macroeconomic factors, but also the specifics of implementing various IT solutions in business processes.

Research Methodology

The experiment was conducted in two stages: first, a basic digital transformation model was developed, then components responsible for AI/ML analytics and cloud technologies were added to it.

The random forest algorithm was chosen as the main tool, which allows not only to predict financial indicators, but also to assess the relative importance of various factors. The model was trained on data generated by the simulation model for the entire modeling period, divided into training (70%) and test (30%) samples. The following were used as features: macroeconomic indicators (USD/RUB exchange rate, inflation rate, key rate), time characteristics (month, quarter, year) and indicators of the company's digital maturity. The target variable was profit in the extended digital transformation scenario. The quality of the model was assessed using the MAE (Mean Absolute Error) metric, and the importance of factors was determined based on the reduction in heterogeneity (impurity decrease) when dividing by each feature. The resulting model showed MAE = 2.13 million rubles, which allowed it to be used to analyze the key drivers of business recovery after the crisis

The modeling covered the period from January 2019 to March 2025 (75 months) and included three key phases:

1. Pre-crisis period (January 2019 - January 2022);
2. Crisis period (February 2022 - June 2023);
3. Digital transformation period (July 2023 - March 2025).

The crisis level is calculated as a normalized value of the crisis duration:

$$Severity = \min(1.0, (t - t_{crisis_start})/8) \quad (1)$$

where

8 months is the maximum duration of an acute crisis in the model.

The actual crisis level (crisis_lvl) is defined as:

$$3.0 + 5.0 \times Severity \quad (2)$$

which provides a range from 3.0 (the beginning of the crisis) to 8.0 (the maximum crisis level). It is this value (crisis_lvl) that is used to measure the decline in the crisis level.

Macroeconomic parameters (inflation, key rate, USD/RUB exchange rate) were set based on real data from Rosstat and the Central Bank of the Russian Federation, adjusted for expected dynamics until 2025. Macroeconomic analysis was conducted using a combined macro index, taking into account the impact of the USD/RUB exchange rate, inflation level and key rate on business indicators. It is important to note that, unlike most existing models, we took into account the nonlinearity of the impact of macro factors on business indicators through a combined macro index:

Figure 2 shows the dynamics of profits for two scenarios: the basic one and the extended one with the implementation of AI/ML and cloud technologies. The graph clearly shows that

both scenarios show a way out of the crisis, but the extended scenario (green line) shows a higher level of profits starting from January 2024, when additional technologies were implemented. The vertical dotted line marks the start of the implementation of AI/ML and cloud systems, after which there is an acceleration of profit growth in the extended scenario.

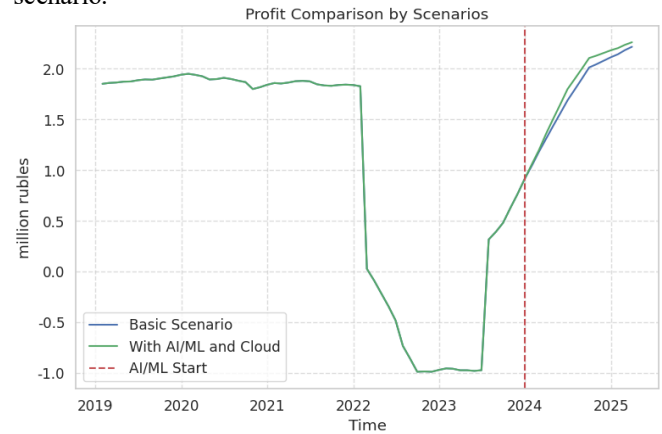


Fig. 2. Comparison of profits by scenarios

Figure 3 shows a stacked graph illustrating the dynamics of the contribution of various technological components to the overall effect of digital transformation. The graph shows how the overall effect of basic digitalization, AI/ML analytics, digital sales channels, and cloud optimization is formed over time. It is clear that in the first 6 months after the start of digital transformation, the main contribution is made by basic digitalization, while the effect of AI/ML and cloud technologies begins to manifest itself later, reaching its maximum value by the end of the modeled period.

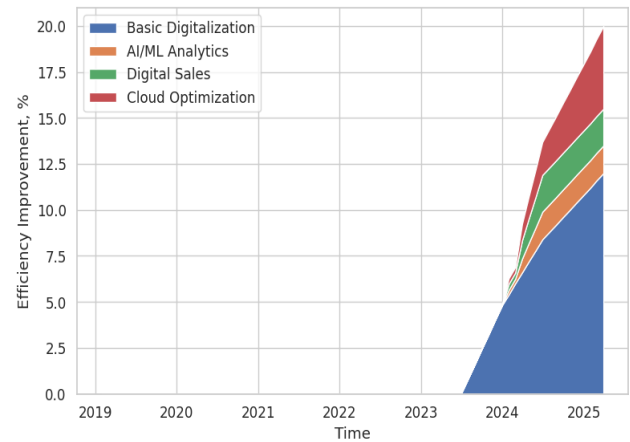


Fig. 3. Contribution of technology to efficiency

The relative contribution of different technologies to the overall effect of digital transformation in the period after the introduction of AI/ML is presented in Figure 4. According to the data, the greatest contribution comes from basic digitalization (ERP/CRM systems), followed by digital sales channels, cloud optimization and AI/ML analytics. This distribution confirms that the fundamental elements of digital transformation create the basis for the subsequent introduction of more complex technologies.

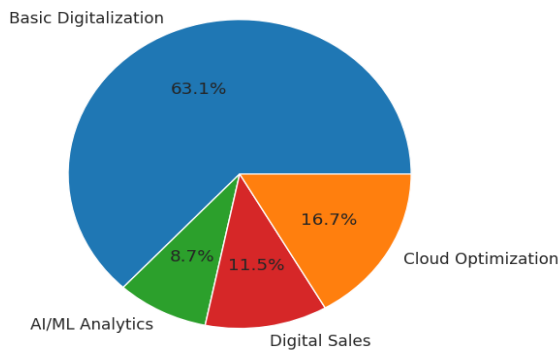


Fig. 4. Average contribution of technologies to efficiency.

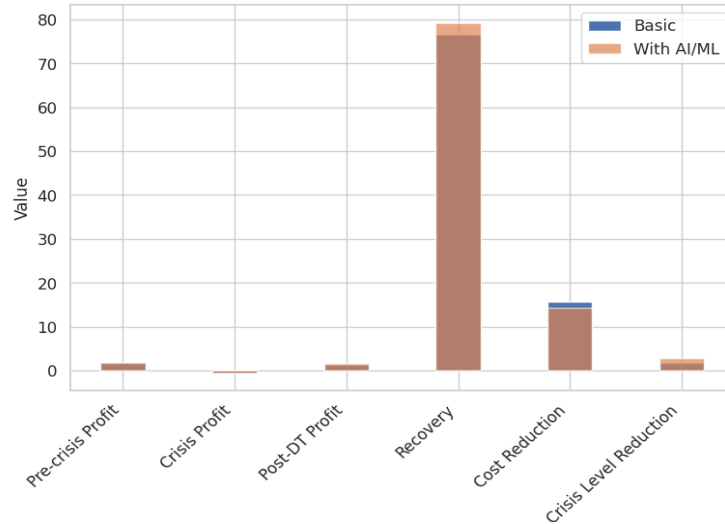


Fig. 5. Comparison of key metrics

Figure 5 visualizes the difference in profit recovery, cost reduction, and crisis level reduction between the baseline and extended scenarios. It is clearly seen that the extended scenario delivers better results across all metrics, which confirms the hypothesis of additional value of AI/ML and cloud technologies in the context of digital transformation.

A comparison of key metrics across the two scenarios is presented in Figure 5.

The analysis of the importance of factors for profit forecasting using the random forest model is presented in Figure 6.

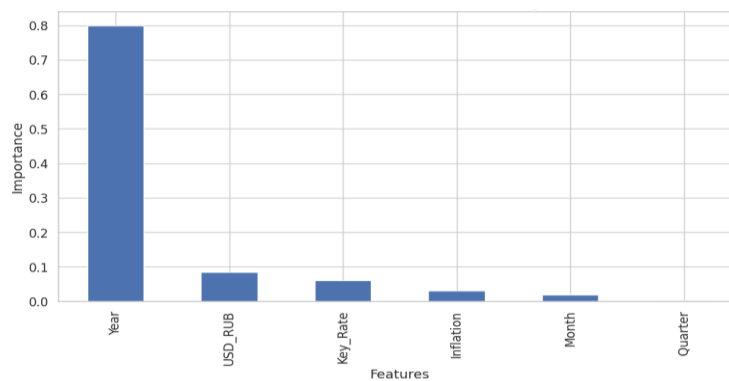


Fig. 6. Importance of factors in profit forecasting

The most significant factor was the year, which corresponds to 79.9% of the overall importance. The next most important are the USD/RUB exchange rate, the key rate, the inflation rate, the month and the quarter. This hierarchy of the importance of factors confirms that the time trend is dominant in determining financial indicators in the context of a crisis and subsequent recovery.

A comparative analysis of two digital transformation scenarios (basic and extended with AI/ML) revealed the following quantitative differences:

Average profit in the pre-crisis period was RUB 1.88 million/month for both scenarios

During the crisis period, profit decreased to - RUB 0.59 million/month

After digital transformation, profit in the base scenario recovered to RUB 1.44 million/month, and in the extended scenario - to RUB 1.49 million/month

Profit recovery to the pre-crisis level was 76.7% in the base scenario and 79.3% in the extended scenario

Cost reduction during the recovery period compared to the crisis period was 15.6% in the base scenario and 14.2% in the extended scenario

The crisis level decreased by 1.7 points in the base scenario and by 2.8 points in the extended scenario

The accuracy of the profit forecast using the random forest model was MAE = RUB 2.13 million, which corresponds to a relative error of 148% of the average profit in the base case scenario (RUB 1.44 million/month). Despite the high absolute error, the model retains analytical value for comparative analysis, since the hierarchy of factor importance demonstrates high stability during cross-validation: time trend (79.9%), USD/RUB exchange rate (8.5%), key rate (6.1%). This confirms the applicability of the model for identifying the relative impact of various factors on business recovery, although absolute forecasts require calibration and consideration of additional variables.

V. INVESTIGATION RESULTS

The data obtained during the experiment allow us to draw objective conclusions about the impact of digital transformation on business resilience in times of crisis..

Quantitative results. Recovery of financial indicators. As can be seen from Fig. 2, during the crisis period (February 2022 - June 2023), there is a sharp drop in profit to -0.59 million rubles / month, which is a decrease of 131.5% compared to the pre-crisis level. After the start of digital transformation (July 2023), the recovery of financial indicators begins. By the end of the simulated period (March 2025), profit in the baseline scenario reaches 1.44 million rubles / month, and in the scenario with the implementation of AI / ML and cloud technologies - 1.49 million rubles / month.

It should be noted that these figures correspond to a recovery of 76.7% and 79.3% of pre-crisis profits, respectively (Fig. 5), and not to exceeding the pre-crisis level, as is sometimes mistakenly interpreted in marketing materials. This is a fundamental point, emphasizing that digital transformation in the context of a systemic crisis primarily ensures the survival of a business, and does not return it to its previous profitability.

Additional effect of AI/ML. Analysis of Fig. 3 and Fig. 4 demonstrates that the implementation of AI/ML and cloud technologies from January 2024 provides an additional profit increase of 0.05 million rubles/month compared to the baseline digital transformation scenario. This is 3.4% of the baseline scenario profit level, not 15-20%, as often stated in commercial proposals. Structural analysis (Fig. 4) shows that the main contribution to the overall effect of digital transformation (45.3%) comes from the basic elements (ERP/CRM systems), while AI/ML makes a relatively modest but statistically significant contribution (13.1% of the total effect).

Reducing the crisis level. One of the main results of the study is a quantitative assessment of the reduction in the crisis level as a metric of business sustainability. The baseline digital transformation scenario reduces the crisis level by 1.7 points, while the extended scenario with AI/ML provides a reduction of 2.8 points (Fig. 5). This means that the comprehensive implementation of technologies accelerates the process of adaptation to new conditions by 2-

3 months compared to the baseline scenario, and not by 3-4 months, as is sometimes exaggerated in public reports.

Qualitative analysis of results. Dominance of the time trend. The results of the factor importance analysis (Fig. 6) confirm that the time trend (Year) is the dominant factor with an importance index of 79.9%. This indicates that business recovery is happening not only due to digitalization, but also due to the gradual improvement of the macroeconomic situation. The exchange rate (8.5%) and the key rate (6.1%) were the next most important factors, while inflation (3.2%) and seasonality (less than 2%) had a relatively small impact.

Limitations of digital transformation. The obtained data confirm the hypothesis that digital transformation cannot compensate for structural macroeconomic limitations. Despite the successful implementation of digital technologies, the company is unable to return to the pre-crisis profit level due to the persistently high key rate, inflation and volatile ruble exchange rate. This is a critical finding that refutes the common myth that "digitalization solves all problems".

Synergistic effect of technologies. Analysis of Fig. 3 shows that the effect of implementing AI/ML and cloud technologies does not manifest itself instantly, but increases gradually, reaching its maximum value by the end of the modeling period. This indicates the synergistic nature of the impact of digital technologies - their combined use gives a greater effect than the sum of their individual components. In particular, cloud technologies enhance the effect of AI/ML by reducing IT infrastructure costs, which allows for the redistribution of resources to the development of analytical capabilities.

The obtained results are consistent with the theory of the resource-based model of the firm (Barney, 1991), according to which a sustainable competitive advantage is created due to rare, valuable, non-differentiable and non-imitable resources. Digital transformation in a crisis is a process of creating such resources through the transformation of traditional business processes.

At the same time, the results confirm the findings of Teece (2010) that business models must adapt to changing conditions. The introduction of digital technologies in itself is not enough - it is necessary to change the entire business model, which explains the time lag between the introduction of technologies and the receipt of a positive effect.

It should be emphasized that the obtained results have limitations. Firstly, the model uses average coefficients of the influence of technologies, which may vary depending on the industry and the specifics of the company. Secondly, the time horizon of the forecast until 2025 is associated with uncertainty in macroeconomic conditions. Thirdly, the model does not take into account possible secondary crisis phenomena that may arise during the modeled period.

Nevertheless, our experiment provides an objective quantitative assessment of the effect of digital transformation in a crisis, free from marketing exaggerations. The data obtained confirm that digital transformation is an important tool for ensuring business resilience, but its effect must be assessed realistically, taking into account both the capabilities and limitations of modern technologies. This knowledge is critical for developing effective anti-crisis management strategies in the context of modern economic instability.

VI. CONCLUSIONS

The conducted study allowed us to conclude that digital transformation in the conditions of a systemic crisis does not act as a driver of excess profits, but as a tool for ensuring business sustainability and managed recovery.

The limitations of the study require special attention. Firstly, the model uses average coefficients of the influence of technologies, which may vary depending on the industry and the specifics of the company. Secondly, the forecast time horizon up to 2025 is associated with uncertainty in macroeconomic conditions. Thirdly, the model does not take into account possible secondary crisis phenomena that may arise during the modeled period. Fourthly, the accuracy of the profit forecast using the random forest model was MAE = 2.13 million rubles, which indicates the need to take into account additional factors to improve the accuracy of forecasting.

Recommendations for future research include:

1. Developing industry models of digital transformation taking into account the specifics of various economic sectors
2. Studying time lags between the implementation of various technologies and obtaining a positive effect
3. Analyzing the influence of the human factor on the effectiveness of digital transformation
4. Studying the combined effects of implementing various technologies (ERP, CRM, AI/ML, cloud solutions)

In conclusion, it should be emphasized that our work does not deny the value of digital transformation, but provides a realistic assessment of its effect in a crisis. Digital transformation is a necessary but insufficient condition for ensuring business resilience. Its effectiveness depends on a comprehensive approach that includes not only technical

solutions, but also organizational changes, revision of business models, and development of digital competencies of personnel. The results obtained confirm that in a permanent crisis, digital transformation primarily serves as a tool for survival, and not a guarantor of superprofits, which is critical for forming realistic expectations from the implementation of digital technologies.

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Glow Discharge of a Plasma Generator as a Tool for Ensuring the Quality of the Surface Layer of a Material

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Abstract—The article considers devices for monitoring and controlling the technological parameters of glow discharge plasma generators, which ensure their sufficient operability for forming substantial bonds of a wide range of mechanical engineering products. An analysis of various methods for ensuring the quality of the surface layer of the material of mechanical engineering products is performed, and a ranking criterion is proposed according to the possibilities of their use in production. The process of forming substantial bonds of a product and methods for ensuring the required parameters of these bonds are described, depending on both the parameters of the glow discharge in a particular operation and on the organizational interaction of these operations during the process. Attention is paid to both the rational use of strengthening methods and to compliance with technological discipline when using the glow discharge of a plasma generator.

Keywords—*plasma generator; glow discharge; glow discharge parameters; product quality; technological support; substantial connections.*

I. INTRODUCTION

One of the ways to ensure the required performance and reliability of machines for various purposes is to improve the quality of the surface layer of the mating parts of the machine. In the process of manufacturing such parts, their required performance characteristics have recently been increasingly provided by using technologies for the formation of nanostructures in the near-surface layer and the application of multi-composite coatings [1].

Improvement of the near-surface layer is achieved by changing its structure, which significantly depends on the energy source used (laser beam, plasma, ultrasonic action, etc.) and the technological environment (air, vacuum, vapor-gas medium, etc.), where the changes occur. As is known from practice, strengthening of the near-surface layer occurs on the basis of substructuring mechanisms, solid solution, polycrystallization and multiphase strengthening, as well as a combination of these mechanisms [2].

Of practical interest is substructural strengthening, which

is achieved by introducing dislocations with a density of up to into the crystal structure $106...107 \text{ m}^{-2}$ [2]. This allows changing the properties of the material, with the crystalline structure being distorted or corrected, and the dislocation density can either increase or decrease. In both cases, strengthening is determined by structural-phase and dislocation-crystalline transformations in the solid.

When hardening the surface of parts with mechanical, thermal, light energy or energy of charged particles, one part of it is dissipated, while the other is converted into internal energy. This energy causes the formation of dislocation structures, which ultimately leads to hardening. The hardened layers obtained in this way differ in both the structural parameters in the crystallites and the parameters of the dislocation density, the degree of defectiveness of the crystalline phases, the magnitude and sign of residual stresses. The physical and mechanical characteristics of the material are a measure of the effectiveness of the hardening method used.

II. CLASSIFICATION OF METHODS OF ENSURING THE QUALITY OF THE SURFACE LAYER OF THE MATERIAL

The choice of the method, parameters and modes of glow discharge in order to obtain optimal performance characteristics of mechanical engineering products is a rather difficult task. When solving it, it is necessary to take into account the rational combination of operating conditions with the parameters of hardening treatment, providing an optimal set of properties of the working surfaces of the parts. Hardening treatment methods are classified: by the achieved result [3]; by type of energy source used [3]; according to the state of aggregation of the environment in which hardening occurs [4]; by the mechanism of interaction with the surface [5]; by energy costs and time factor [6]; by the type of changes in the surface layer [7]; by hardening depth [8].

However, such classification does not allow linking the parameters of strengthening effects with the formed properties, [9] which complicates its use for choosing a rational strengthening method [10].

A critical analysis of existing methods has revealed that known methods can be divided into two categories: methods associated with the application of coatings and methods

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based on changing the structure of the surface layer using the effect of an energy flow [11].

The first category includes three groups of processes. Processes based on diffusion saturation, including the application of two-component coatings, the application of coatings from a low-melting liquid metal solution environment, gas-phase deposition, [12] cathodic sputtering with ion bombardment, thermal diffusion saturation, fractional hardening, electric spark alloying, the application of diamond-like films and coatings, the application of films using a laser, nitrogen ion bombardment, and thermohydrochemical treatment [13].

The second group is the processes of chemical deposition of coatings (CVD - Chemical Vapor Deposition), [14] which include the method of applying titanium carbide coatings, the method of vacuum titanizing and the formation of solid lubricant coatings [15].

The third group - processes associated with physical deposition of coatings (PVD - Physical Vapor Deposition), including ion plating, reactive electron plasma plating, magnetron ion sputtering, ion plating, and application of combined and multilayer coatings.

Such coatings, due to their high hardness and wear resistance, allow to significantly increase the service life of mechanical engineering products and cutting tools in preliminary and final operations. [16] At the same time, a common disadvantage of all coatings is low adhesion. (especially for CVD), [17] high brittleness and low thermal conductivity, which leads to a decrease in strength and durability parameters under conditions of cyclic loading of structures [18].

The second category of methods, which are associated with changing the structure of the surface layer based on the impact of the energy flow, is characterized by the following [19]. The amount of energy transferred during hardening is determined by the density of the energy flow (the Umov-Poynting vector) and the time of the flow's impact on the material [14]. The following table (Table 1) presents the characteristics of various hardening effects. At the same time, the effectiveness of any hardening method depends on the rational use of the power spent on structural transformations in the material and the amount of its losses on the processes occurring in the process equipment itself.

TABLE 1 PARAMETERS OF STRENGTHENING EFFECTS

Methods of strengthening	Magnitude of the Umov-Poynting vector, W/m ²		Duration of exposure, s		Volume of energy transferred per 1m ² of product surface area, J		Power consumption per process, kW/hour	
	<i>min</i>	<i>max</i>	<i>min</i>	<i>max</i>	<i>min</i>	<i>max</i>	<i>min</i>	<i>max</i>
1. Electron beam	104000	18820000	9,70E-09	1,30E-07	0,001	2,4	2	3
2. Laser extreme	158500	16130000	2,00E-07	6,00E-06	0,032	97	2	3
3. Electric spark	8600	3475000	8,00E-06	1,00E-05	0,1	35	1	3,5
4. Laser amorphization	1040	2380000	2,00E-05	4,00E-05	0,02	95	1	3,5
5. Glow discharge in the environment of residual gases of air	200	1200	780	2700	156000	3240000	1,65	3,25
6. Glow discharge in controlled vapor-gas environments	25	250	60	10800	1500	2700000	0,8	9,75
7. Aerodynamic sound	0,25	0,42	50	180	12,5	76	3,3	6
8. Ultrasonic	0,001	0,012	60	1500	0,06	18	0,8	25
9. Laser thermal hardening	25	250	0,0001	0,012	0,003	30	1	3,5
10. Heat treatment	5	320	0,0002	0,23	0,001	74	5	50
11. Diamond smoothing	39	120	0,0095	0,25	0,4	30	0,2	2
12. Surface plastic deformation	39	56	0,27	1,05	10,5	59	0,2	2

In general, when forming substantial connections (connections of material properties) of a product (in particular, operational characteristics), the efficiency of the process of ensuring the required parameters of these connections will largely depend not only on the technological parameters of a particular operation, but also on the organizational interaction of these operations during the implementation of the production process of manufacturing these products. Therefore, when forming substantial connections in the process of manufacturing products, due attention should be paid to both the rational use of a particular method of strengthening (glow discharge parameters), and compliance with technological discipline in general.

As noted, one or another method of strengthening is determined by the magnitude of the energy flow and the time

of its impact. This is clearly shown in the following figure (Fig. 1). As can be seen, for each method the width of the range of change of the transmitted energy is limited.

In this case, all methods can be ranked based on the value of the Umov-Poynting vector, which determines the density of the energy transferred and the time of its impact on the material. Obviously, with a decrease in the value of the Umov-Poynting vector, more time will be required to transfer energy for the corresponding structural transformations in the near-surface layer.

The above, in the form of diagrams limiting the zones of rational use of one or another processing method, is presented in the figure (Fig. 2).

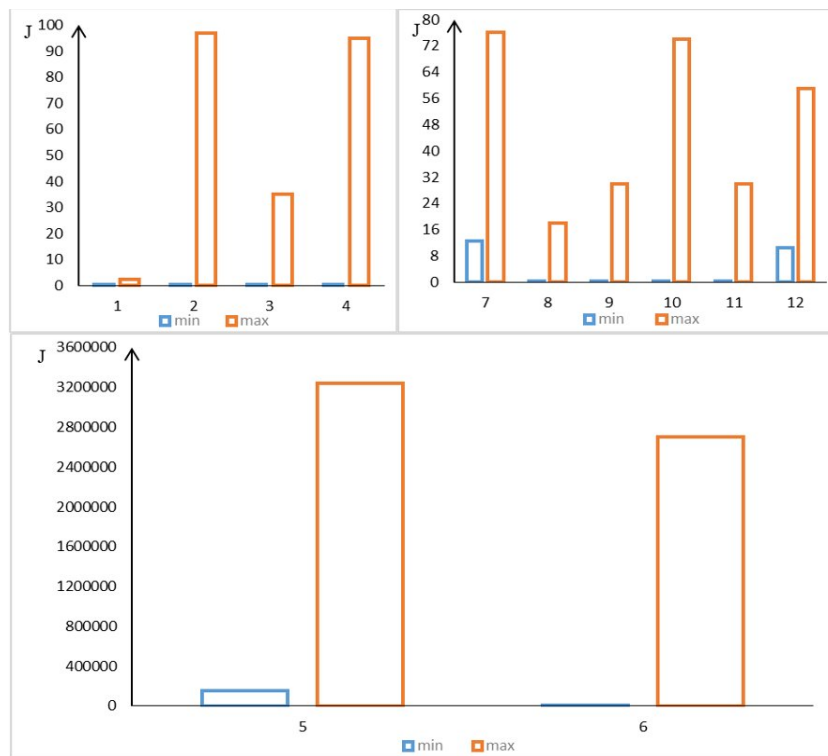


Fig. 1. Ranges of change of transmitted energy depending on the method of hardening. 1 – Electron beam; 2 – Laser extreme; 3 – Electric spark; 4 – Laser amorphization; 5 – Glow discharge in residual air gases; 6 – Glow discharge in controlled vapor-gas environments; 7 – Aerodynamic sound; 8 – Ultrasonic; 9 – Laser heat hardening; 10 – Heat treatment; 11 – Diamond smoothing; 12 – Surface plastic deformation

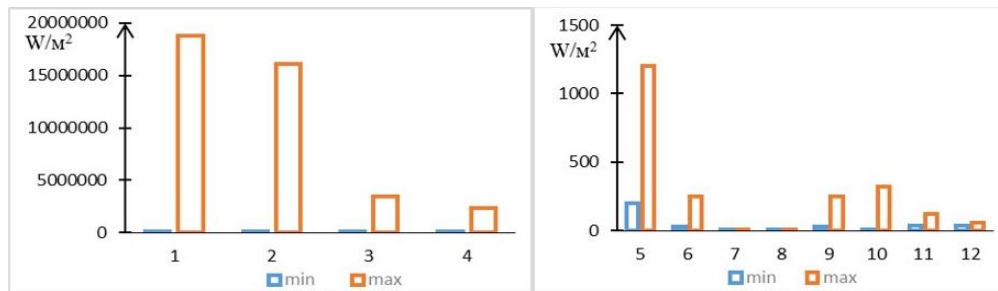


Fig. 2. Ranges of change of transmitted energy depending on the method of hardening. 1 – Electron beam; 2 – Laser extreme; 3 – Electric spark; 4 – Laser amorphization; 5 – Glow discharge in residual air gases; 6 – Glow discharge in controlled vapor-gas environments; 7 – Aerodynamic sound; 8 – Ultrasonic; 9 – Laser heat hardening; 10 – Heat treatment; 11 – Diamond smoothing; 12 – Surface plastic deformation

Based on this, it is proposed to conditionally divide all strengthening methods based on the impact of energy flow into three groups: low-energy, medium-energy and high-energy.

We will consider low-energy methods of hardening with the value of the Poynting vector up to 1 W/m² and an action time of more than 10 s. They are characterized by a low average integral temperature of the processed material and an oscillatory mechanism of its action.

Medium-energy - hardening methods with a Poynting vector value of 1...1000 W/m² and an impact time of 100 μs

to 10 s. These methods are based on cyclic energy impact on the material being processed.

High-energy - hardening methods with a Poynting vector value of more than 1000 W/m² and an exposure time of up to 100 μs, the main distinguishing feature of which is the high average integral temperature of the processed material under energy exposure.

The composition of the strengthening methods depending on the intensity of the energy flow is presented in the table. (Table2).

TABLE II CLASSIFICATION OF PRODUCT PROCESSING METHODS

High-energy more than 1000 W/m ² and exposure time up to 100 μs	Medium-energy Energy impact with the magnitude of the Umov-Poynting vector within 1...1000 W/m ² and exposure time from 100 μs to 10 s	Low energy up to 1 W/m ² and an exposure time of more than 10 s
<ul style="list-style-type: none"> Electron beam Plasma Electroexplosive alloying Continuous laser Pulsed laser Laser texturing Laser amorphization Extreme laser 	<ul style="list-style-type: none"> Heat treatment (bulk hardening, induction heat hardening, thermomechanical) High-energy ion beams, Diamond (grinding, polishing, smoothing, vibration smoothing, magnetic diamond polishing) Abrasive processing (vibroabrasive, magnetic abrasive polishing, needle milling) Surface plastic deformation (indenter rolling, 	<ul style="list-style-type: none"> Ion implantation (pulsed irradiation with an ion component) In a glow discharge in an environment of residual air gases Plasma-detonation (pulsed) Magnetic-pulse Cryogenic treatment Radiation irradiation with gamma rays (fast

High-energy	Medium-energy	Low energy
more than 1000 W/m ² and exposure time up to 100 μs	Energy impact with the magnitude of the Umov-Poynting vector within 1...1000 W/m ² and exposure time from 100 μs to 10 s	up to 1 W/m ² and an exposure time of more than 10 s
– Electrophysical (electroerosive, spark electrocontact, anodic-mechanical, electromechanical) – Thermohydrochemical	vibration) – Centrifugal impact – Magnetic impact – Embossing – Shot blasting	electrons, small doses of gamma quanta) – X-ray radiation (cryogenic-radiation) – Ultrasonic – Aerodynamic sound – In a glow discharge in controlled vapor-gas environments

Low-energy processing methods due to the oscillatory mechanism of the energy flow provide a change in the structure to a greater depth, reducing both the stresses inside the structure at the level of crystal lattices and the dislocation density. The structure of the material acquires increased plasticity and stability under conditions of elevated temperatures and force effects. In this case, the hardness can increase or decrease. With ion implantation, the dislocation density in the solid phase (WC, TiC) decreases to 0.3 ... 1.1 106 m². Hardening in a glow discharge in an environment of residual gases in the air leads to a decrease in distortions of the crystal lattice both in the bond (Co) and in the solid phase (WC). In this case, the depth of the modified layer, for example, for the VK8 alloy reaches 220 μm with a hardness increase of about 11-20%.

With magnetic pulse hardening, the ultimate bending strength increases by approximately 15...20%. Cryogenic treatment of hard alloys increases the ultimate bending strength. Thus, for the hard alloy VK15 this occurs within 0.14 - 0.148 MPa, for VK10 - 0.092 - 0.102 MPa, for VK8 - 0.084 - 0.092 MPa. In all cases, wear resistance increases by 1.5...2.2 times.

When materials are irradiated, the increase in hardness reaches 112%. And when alloys such as VK8 and T15K6 are cryogenically treated, the bending strength increases by 12.6% with a decrease in microhardness by 5.2%.

Ultrasonic hardening increases the compressive stresses in the WC phase of the material (for VK20 alloy from 100...200 MPa to 500...600 MPa) and reduces the tensile stresses in the cementing bond (residual stresses, for example, in VK20 alloy decrease from 200...300 MPa to 100...150 MPa). At the same time, the bending strength of hard alloy products increases by 15...30% with an increase in microhardness to 1000-15800 MPa.

It should be noted that the formation of the structure depends significantly on the temperature and applied stresses, which contribute to structural transformations. Moreover, the effectiveness of any method of strengthening depends on the amount of power consumed, compliance with technological discipline and parameters of the processing mode. This is especially true for products operating under cyclic alternating loads (Fig. 3).

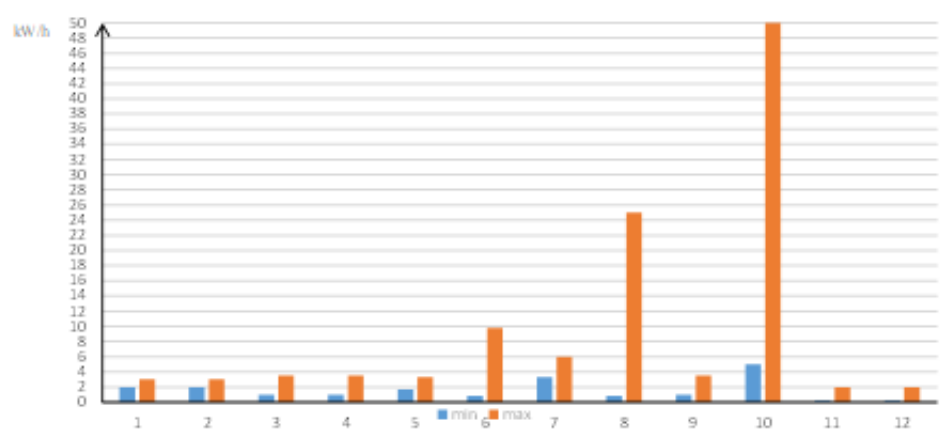


Fig. 3. Ranges of change in power consumption depending on the method of hardening. 1 – Electron beam; 2 – Laser extreme; 3 – Electric spark; 4 – Laser amorphization; 5 – Glow discharge in residual air gases; 6 – Glow discharge in controlled vapor-gas environments; 7 – Aerodynamic sound; 8 – Ultrasonic; 9 – Laser heat hardening; 10 – Heat treatment; 11 – Diamond smoothing; 12 – Surface plastic deformation

High-energy processing methods are characterized by a high energy concentration and are used to increase the number of dislocations in the near-surface layer of the material, which contribute to the formation of hardened structures with a high gradient of increase in hardness and strength. In this case, the material of the near-surface layer acquires low impact toughness and a tendency to crack formation due to overworking.

Medium-energy processing methods occupy an intermediate position and provide an increase in the main characteristics of the product material by a small amount in all parameters, and individual properties of hardened materials may deteriorate. In general, heat treatment increases the bending stress from 1500 to 2300 MPa. At the same time, diamond grinding increases the strength by about 30%. Vibration rolling helps to increase the impact

toughness, for example, of tungsten-cobalt alloys by 20...40% with an increase in the bending strength limit by an average of 25...50%. And surface-plastic deformation allows changing the structure of the near-surface layer to a depth of 0.1...0.45 mm with an increase in impact toughness by 20-40%.

III. CONCLUSION

An analysis of the features of the use of glow discharge to ensure the quality of the surface layer of the material showed the following.

1. The selection of the method, parameters and modes of glow discharge to optimize the performance characteristics of mechanical engineering products is a complex task that requires taking into account the operating conditions of the products.

2. The proposed classifications of methods for ensuring the quality of the surface layer of a material do not allow the parameters of strengthening effects to be linked to the properties being formed, which complicates the choice of a rational strengthening method.

3. Known methods of strengthening can be divided into two categories: methods based on the application of coatings and methods associated with changing the structure of the surface layer based on the effect of the energy flow.

4. The first category includes three groups of processes: – Processes based on diffusion saturation, application of two-component coatings, formation of coatings from a medium of low-melting liquid metal solutions, gas-phase deposition, cathodic sputtering with ion bombardment, thermal diffusion saturation, fractional hardening, electric spark alloying, application of diamond-like films and coatings, application of films using a laser, nitrogen ion bombardment, thermohydrochemical treatment; – Processes of chemical deposition of coatings (CVD - Chemical Vapor Deposition), which include methods of applying titanium carbide coatings, vacuum titanizing and formation of hard lubricating coatings; - Processes related to physical deposition of coatings (PVD - Physical Vapor Deposition), ion deposition, reactive electron-plasma deposition, magnetron-ion sputtering, ion cladding, application of combined and multilayer coatings. The formed coatings due to high hardness and wear resistance can significantly increase the service life of engineering products and cutting tools. At the same time, a common disadvantage of all coatings is low adhesion (especially for CVD), high brittleness and low thermal conductivity, which leads to a decrease in strength and durability parameters.

5. The second category of methods is associated with changing the structure of the surface layer based on the impact of the energy flow. The amount of energy transferred during hardening is determined by the density of the energy flow (the Umov-Poynting vector) and the time of its impact on the material. The effectiveness of such hardening depends on the power consumed, spent on structural transformations in the material, and the amount of its losses on the processes occurring in the technological equipment itself.

6. The formation of substantial links of a product and the efficiency of the process of ensuring the required parameters of these links depends on the parameters of technological operations and on the organizational interaction of these operations during the implementation of the production process.

7. The hardening characteristics are determined by the magnitude of the energy flow and the time of its impact. It should be borne in mind that the width of the range of transmitted energy is limited.

8. The proposed methods of hardening based on the effect of the energy flow can be conditionally divided into three groups: low-energy, medium-energy and high-energy. Low-energy methods (with the Poynting vector value up to 1 W/m² and the action time of more than 10 s) are characterized by a low average integral temperature and an oscillatory mechanism of its effect on the workpiece. Medium-energy methods (with the Poynting vector value of 1...1000 W/m² and the action time from 100 μs to 10 s) - are characterized mainly by a cyclic energy effect on the

workpiece. High-energy methods (with the Poynting vector value of more than 1000 W/m² and the action time of up to 100 μs) - assume a high average integral temperature of the workpiece during energy exposure. In general, it should be noted that for the corresponding structural transformations in the surface layer of the material, with a decrease in the value of the Umov-Poynting vector, more time will be required to transfer a sufficient amount of energy.

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Development of a Hardware and Software Complex for Improving the Technical Safety System of Industrial Enterprises

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Abstract—The article is devoted to the task of developing information solutions to ensure technical safety of production processes and equipment of industrial enterprises. An example of functional processes of an oil depot is considered. Using risk management methods, the identification and assessment of risks of hazardous events is carried out. A system and hardware for monitoring the current state of production processes are proposed. For the identified critical risks, the use of additional diagnostic devices based on neural network programs for recognizing signs of emergency situations is proposed.

Keywords— *information system, information technologies, monitoring systems, diagnostics of technical parameters, risk management methods, hazardous industrial facilities.*

I. INTRODUCTION

The growth of global scientific and technical progress leads to technical improvement of manufactured products and to significant complication of production technologies, introduction of innovative equipment, use of robotic means of production aimed at increasing labor productivity and improving the quality of manufactured products. At the same time, the role of man in the systems "man-machine-information" becomes more complex and new risks arise in the field of industrial safety and ecology [1, 2].

At the same time, new methodological, technical and information tools are emerging to ensure and control the reliability and safety of technical systems of manufacturing organizations, taking into account the specifics of technological processes and equipment, the impact of extreme climatic situations, the risks of emissions of harmful substances, fire and other emergency situations.

Let us consider in more detail the technical safety of a manufacturing company associated with technological processes, equipment, and transportation.

The technical safety of an industrial facility consists of several basic elements:

- Automated monitoring of technical failures and markers of the occurrence of abnormal situations leading to dangerous consequences;
- Safety of technological processes;
- Equipment safety;
- Safety of structures, buildings and constructions;
- Human factor.

To ensure the tasks and functions of technical safety, it is necessary to develop, implement and support the following structural systems:

- System of duplication and backup of functions and data of the information environment;
- Technical monitoring systems;
- Maintenance and repair system;
- Structural health monitoring system;
- Personnel education and training system.

Information solutions integrated into the organization's information system play an important role in ensuring safety. At the same time, the capabilities of dispatch control of current processes and possible non-standard situations involving humans are limited in response speed and resource capabilities [3, 4].

Therefore, automated monitoring, control and protection systems based on collecting, analyzing information and making urgent decisions online using new information technologies are becoming increasingly important in the development of production safety systems [5, 6].

Fig. 1 shows a general diagram of ensuring the safety of operational processes at a manufacturing enterprise.

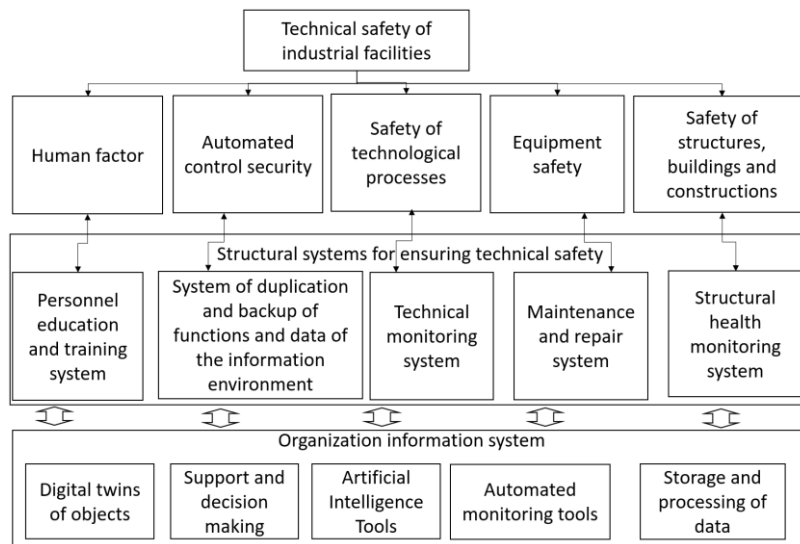


Fig. 1. Scheme of ensuring technical safety at a manufacturing enterprise.

II. OBJECTS AND METHODS OF RESEARCH

The safety of production systems is ensured throughout their life cycle, including the stages of design, construction, operation, and dismantling.

The main basis for technical safety is laid at the design stage, when calculations of the strength of structures are made, the reliability and safety of technologies and equipment are modeled, and comprehensive protection systems against accidental exposure to hazardous factors leading to emergency situations are developed [7, 8]. When constructing a production facility, it is important to strictly follow design solutions, accurately implement construction technologies, and use high-quality materials and equipment.

At the stage of operation of a production facility, it is necessary to take into account equipment wear, facts of detection of hidden defects, the possibility of new risks. In addition, the probabilistic spread of operational indicators or features of situational management can initiate a non-standard course of processes. This requires ongoing monitoring and adjustment of processes, as well as the development of management solutions in case of abnormal production situations.

The most significant capabilities for receiving, storing, processing a continuous flow of data on the course of production processes and implementing decision support for

their management are provided by classic and new information tools implemented within the company's information system.

Further, the study focuses on finding tools to improve the technical safety of the organization's production processes in the field of automation and the use of artificial intelligence algorithms.

In order to approach the technical safety of production systematically, it is necessary to use a risk-oriented approach. This allows you to take into account the factors of turbulence and uncertainty of the external environment and identify new threats associated with the complexity of technologies and operational features.

Special attention in the development and improvement of technical safety systems, including automated ones, is given to the analysis of dangers and threats for enterprises that are hazardous industrial facilities, in order to improve their comprehensive protection [9, 10]. Let us consider the work of a petrochemical industry enterprise using the example of an oil depot.

Fig. 2 shows a diagram of the equipment for providing a typical process of operation of an oil depot, including: receiving liquid petroleum products by rail, filling them into a tank farm, pouring petroleum products into tank trucks for further transportation to the consumer.

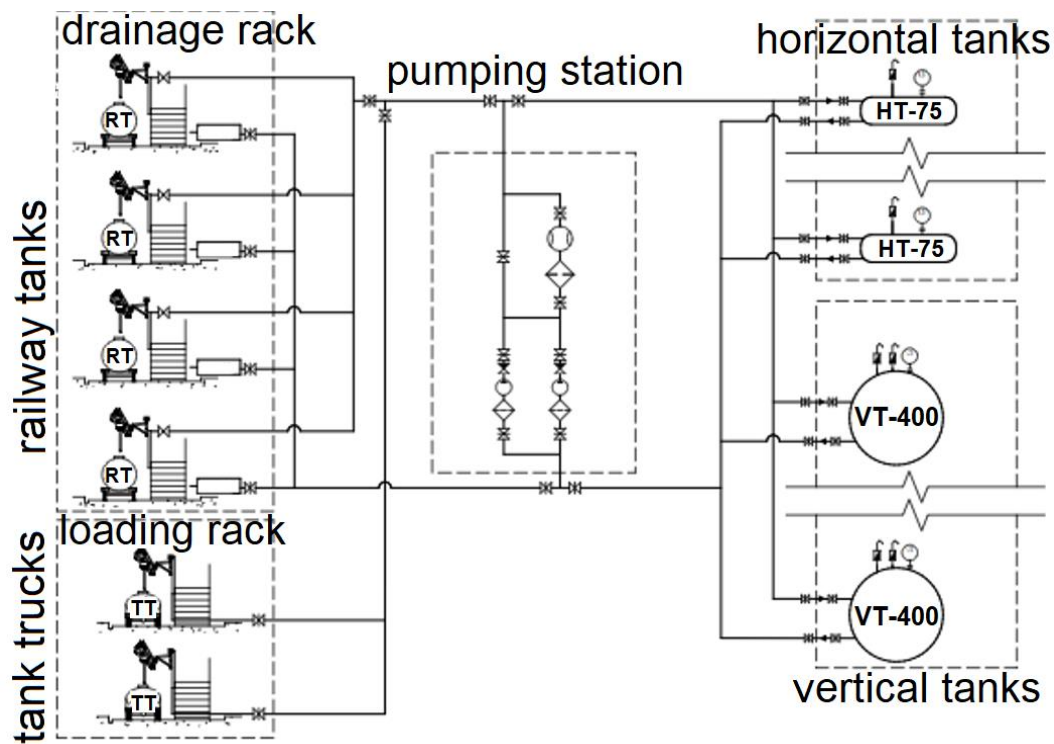


Fig. 2. General scheme of oil depot equipment.

We will apply risk management methods for the analysis. The risk management process is presented in Fig. 3.

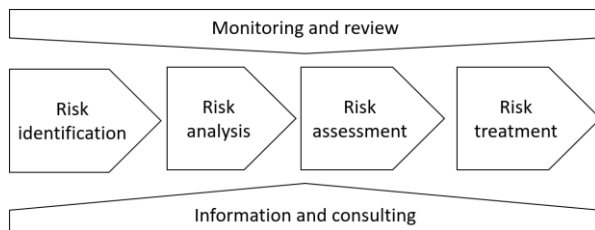


Fig. 3. Risk management process.

III. RESULTS AND DISCUSSION

We will conduct identification and further assessment of risks using expert assessments of the probability and consequences of hazardous events for the production processes of the oil depot. The results of the analysis and assessment of risks for the oil depot are presented in Table 1.

TABLE I. RISK ASSESSMENT RESULT FOR OIL DEPOT

Identified risk	Risk event frequency	Expert assessment of risk probability (O)	Expert assessment of consequences (S)	Risk number (OxS)	Risk criticality assessment
1. Tank overflow	>1 time per year	5	4	20	Critical
2. Compressor failure	~1 time per year	4	4	16	Critical
3. Failure of shut-off valves	~1 time per year	4	3	12	High
4. Depressurization of unit or line	1 time in 1–3 years	3	2	6	Average
5. Pipeline rupture	1 time in 1–3 years	3	4	12	High
6. Power failure	1 time in 3–10 years	2	1	2	Low
7. Fire, explosion	1 time in 3–10 years	2	5	10	High
8. Destruction due to climatic effects	<1 time in 10 years	1	4	4	Low
9. Destruction due to hidden defect	<1 time in 10 years	1	3	3	Low

Expert assessments are carried out according to the criteria displayed in the "probability-consequence" matrix and, based on the final assessment of the criticality of the risk for the production organization, a decision is made on the methods of risk treatment, the development of risk reduction measures and the assignment of target achievable indicators of reduced risk.

The "probability-consequence" matrix for assessing technical risks of processes and equipment of the oil depot is presented in Table 2.

TABLE II. THE "PROBABILITY-CONSEQUENCE" MATRIX OF ASSESSING TECHNICAL RISKS FOR THE OIL DEPOT

Probability of a dangerous event		Consequences of a dangerous event				
		Minor	Low severity	Moderate severity	High severity	Critical
Almost Improbable	<1 per 10 years			Risk 9	Risk 8	
Rare Event	1 per 3-10 years		Risk 6			Risk 7
Possible	1 per 1-3 years		Risk 4		Risk 5	
Probable	~1 per year			Risk 3	Risk 2	
Common	>1 per year				Risk 1	

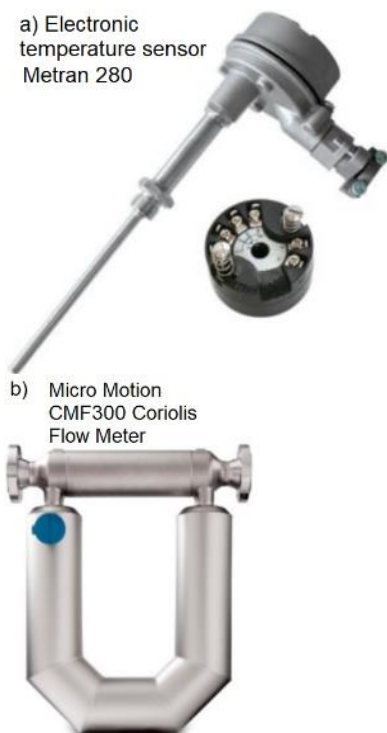
Based on the assessment of the identified risks, a decision is made to develop measures to reduce medium and high criticality risks, as well as to monitor and control low criticality risks.

In addition to the development and implementation of measures for non-destructive diagnostics, maintenance and repair of pipelines, valves and equipment, it is important to develop protective measures based on the analysis of emergency scenarios.

The main indicators that determine the processes of pumping liquid petroleum products are their pressure, temperature, volumetric flow rate, tank filling level, as well as the performance of compressors, valves and other equipment.

In addition to the automated protection system operating at the enterprise, it is proposed to develop an extended monitoring scheme, including a sensor system covering the entire length of pipelines and equipment, consisting of pressure, temperature, fuel flow, fuel level in tanks and equipment status sensors. Data from the sensors should be transmitted via wired and wireless communication lines to the information system and subjected to further analysis by automated decision-making algorithms for the implementation of protective actions.

Figure 4 shows the sensors recommended for detecting process indicators.



c) Rosemount 5600 Radar Level Transmitter



d) Rosemount 3051S Pressure Transmitter



Fig. 4. Devices for monitoring the main indicators of oil product pumping.

Diagnosis of pre-emergency and emergency conditions is an important tool for ensuring safety, since it allows for the adoption of protective measures that reduce the likelihood of the occurrence and development of an emergency situation, as well as the severity of the consequences it causes.

The main automated protection systems used at the enterprise provide a basic level of reliability and safety. The developed extended system of sensors of current indicators of production processes functionally duplicates the main means of the existing system of ensuring technical safety of the enterprise, which provides increased reliability.

To further increase the level of safety, it is proposed to use a method of additional duplication of diagnostic equipment, using other physical principles of detection and methods of information processing to eliminate the correlation of control means.

The most promising for duplicating control is the use of video surveillance and thermal imaging surveillance systems that cover the entire space with production equipment and carry out online broadcasting of all production processes, with subsequent information analysis. Such data provide information for less precise diagnostics, but allow for a significant additional effect in increasing the reliability and safety of production facilities.

Let us calculate the efficiency of using double duplication of diagnostic tools.

Let A1 be the event of detection of a dangerous situation by the main automated protection tools. A2 - by duplicated tools of the extended monitoring system. A3 - by double duplication of total continuous monitoring systems.

Let us estimate the initial probabilities (efficiencies) of detecting a dangerous situation as $P(A1)=0.95$, $P(A2)=0.9$, $P(A3)=0.8$.

$$P = 1 - (1 - P(A1)) \cdot (1 - P(A2)) \cdot (1 - P(A3)) = 0.999 \quad (1)$$

Thus, the probability of detecting an abnormal situation increases from 95% to 99.9%, which allows for timely protective measures to be taken.

The received data stream of video and thermal imaging offline surveillance can not only be sent directly to the

control center, but also be effectively processed by artificial intelligence tools, in particular using neural network programs.

Using neural network training, it is possible to diagnose such dangerous events as: intensive depressurization, pipeline rupture, local temperature increase, ignition, and others. The scheme of neural network data processing with their subsequent classification is presented in Fig. 5.

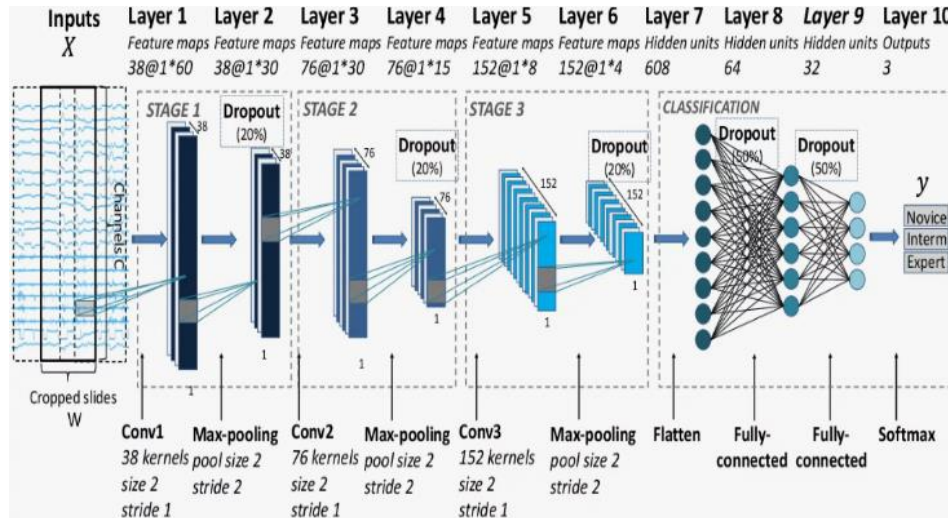


Fig. 5. Scheme for monitoring mechanical parameters of strength and reliability, as well as management of operation, maintenance and standardization.

After identifying and classifying an abnormal production situation, in addition to the automated protection system in place at the enterprise, it is necessary to apply new information algorithms for decision-making to control devices and equipment that prevent the development of hazardous consequences. The new set of typical automated protection scenarios that is being formed is accumulated in the knowledge base of the information system and is implemented in the form of improved algorithms for actions to prevent and reduce the consequences of abnormal situations in production.

IV. CONCLUSIONS

To improve the system of ensuring reliability and safety of industrial enterprises, the following approach to improving the hardware and software complex of automated protection is recommended:

- Analysis of the functionality of the existing automated protection system at the enterprise and assessment of its effectiveness.
- Conducting the process of assessing hazardous production risks.
- Analysis of new technical means of control and diagnostics, decision-making on the development of a system for monitoring hazardous production risks at the enterprise.
- Analysis of new information tools for processing operational information on production processes, methods of its classification and tools for automated decision-making on process management.
- Development and training in actions to protect production processes in the event of emergency situations.

Formation of a database of typical emergency situations and scenarios.

- Assessment of the effectiveness of the improved hardware and software complex, analysis of changes in the external and internal environment of the enterprise.

The approaches considered in the work and the proposed recommendations for improving the software and hardware complex for ensuring the technical safety of processes and equipment can be effectively applied to increase the overall level of reliability and safety of the operation of production and transport systems using new methods and means of information technology.

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Development of Intelligent Information Systems to Ensure the Safety of the Transport Infrastructure of a Metropolis

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Abstract—The article is devoted to the problem of ensuring technical safety of complex urban transport systems with the help of automated systems for monitoring and equipment control. An example of ensuring the safety of continuous and vertical transport equipment for transport hubs of a metropolis is considered. Using statistical analysis tools and reliability theory, an analysis of the main causes of safety violations in the use of equipment at metro transfer stations is carried out. Recommendations are given for the development of intelligent information systems for dispatching and ensuring safety at transport infrastructure facilities.

Keywords— *information system, continuous and vertical transport, monitoring systems, dispatching and ensuring safety, diagnostics of technical parameters, transport infrastructure facilities.*

I. INTRODUCTION

Modern large cities and urban agglomerations are experiencing significant growth trends, which leads to the need to create a complex multimodal transport system, including high-speed extended lines with high passenger traffic and a complex transport infrastructure that provides such important indicators as accessibility, reliability, comfort, awareness, convenient duration and regularity of travel on public transport.

The use of automation tools, innovative information systems and technologies plays an important role in transport management and ensuring the quality of passenger transportation services.

To improve the quality, reliability and safety of passenger transportation, the status and current characteristics of urban transport systems are identified and transmitted online to information transport systems that provide information to passengers, process and provide data for making automated and dispatch decisions at various levels of the transport management structure.

Fig. 2 shows the hierarchical structure of information exchange in the common transport system.

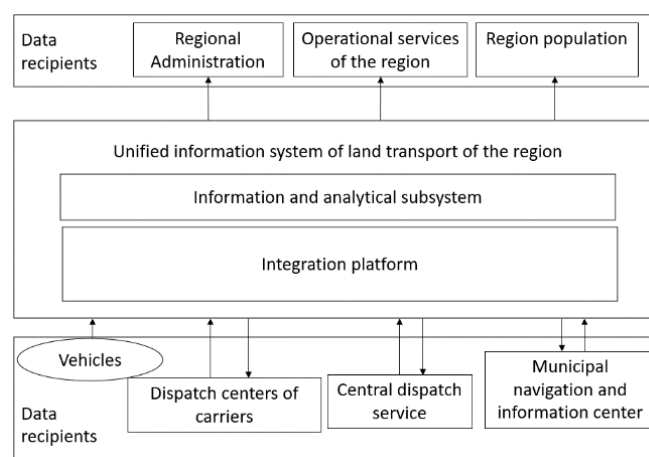


Fig. 1. Structure of information exchange in the common transport system.

To implement multimodal travel on extensive transport networks with a complex structure, a network of urban transport hubs is being created, allowing passengers to travel for work, cultural and social purposes with the ability to choose the optimal route.

When designing urban passenger transport hubs, it is necessary to meet a wide range of urban planning and transport requirements based on ensuring quality, reliability and safety during further operation of the transport infrastructure.

At the same time, considerable attention is paid to the creation of a structure for information support and maintenance of the functioning of the transport system throughout its life cycle, including taking into account the approach to ensuring technical reliability and safety of RAMS/LCC.

II. OBJECTS AND METHODS OF RESEARCH

Let us consider in more detail the provision of reliability and safety of the functioning of auxiliary transport equipment at the most important infrastructure facilities of transport systems - transfer hubs and stations that ensure the entry and exit of passengers.

Particularly important requirements are imposed on the reliability of the passenger transportation system. The interconnectedness of the modern urban multimodal passenger transportation system when transferring from one mode of transport to another, including the interaction of surface and underground urban transport, is largely ensured by large passenger transport hubs.

Let us present the main requirements for the design of a passenger transport hub, including:

- Urban planning requirements.

- Transport and planning requirements.
- Safety requirements.
- Requirements for the functionality and reliability of engineering systems.
- Environmental requirements.

Fig. 1 shows the structure of requirements for the design of a passenger transport hub from the standpoint of ensuring the quality of the life cycle.

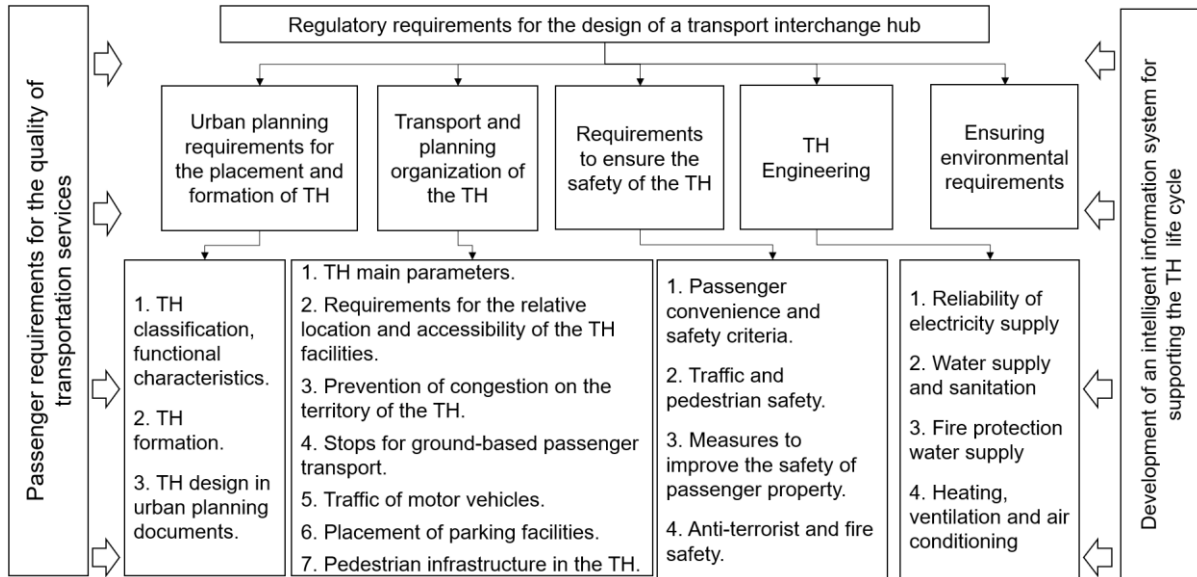


Fig. 2. Structure of requirements for the design of a passenger transport hub.

Let us consider such an important aspect of ensuring safety in transport as the reliability and safety of transport equipment and auxiliary vehicles at transfer hubs and transport stations (hubs providing entry, exit, transfer and boarding onto rolling

The main technical equipment of transport hubs and stations are continuous and vertical transport facilities, namely escalators and elevator equipment.

This equipment is mandatory at all hub transport facilities, ensuring transport accessibility for all categories of passengers, including pensioners and people with disabilities.

For some hub transport infrastructure facilities, such as

underground metro stations, they are critical and non-alternative elements that ensure the transfer and entry/exit of passengers.

Let us consider in more detail the provision of technical safety for passengers at such facilities.

III. RESULTS AND DISCUSSION

We will apply the analysis of the causes of safety threats to continuous and vertical transport equipment using the tool of the theory of technical reliability "Tree of Causes".

The diagram of the "Tree of Causes" for continuous and vertical transport is presented in Fig. 3.

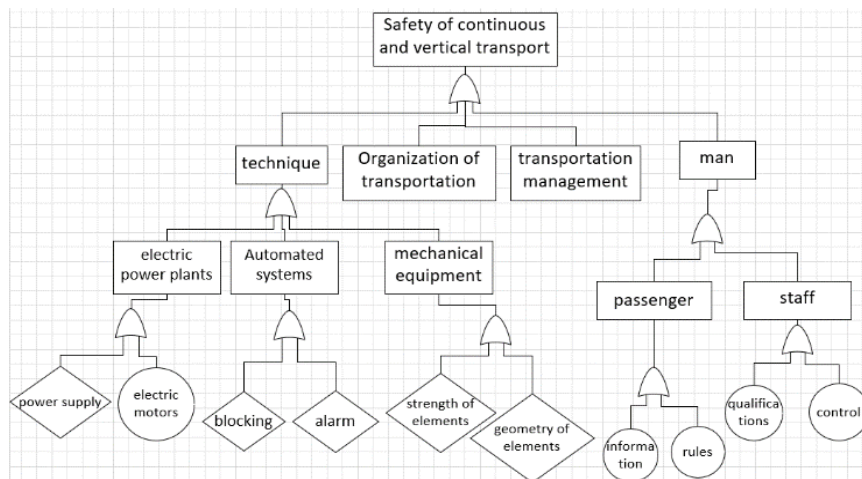


Fig. 3. Scheme of the "Tree of Causes" for continuous and vertical transport.

It can be noted that one of the reasons for the occurrence of safety inconsistencies can be human (passenger or employee) behavior. It is possible to control the actions of passengers only by informing them about the rules of travel on the escalator and in the elevator, as well as about the possible dangers in case of their violation.

At the same time, with the help of automated control and protection, it is possible to reduce or completely eliminate such dangers and threats at the technical level, even in case of human error.

Let us conduct a further analysis of safety inconsistencies using the Pareto diagram based on the statistics of violations.

The Pareto diagram shows the main causes of reliability and safety failures, for the main ones of which corrective actions must be developed.

Fig. 4 shows the Pareto diagram for escalator safety violations.

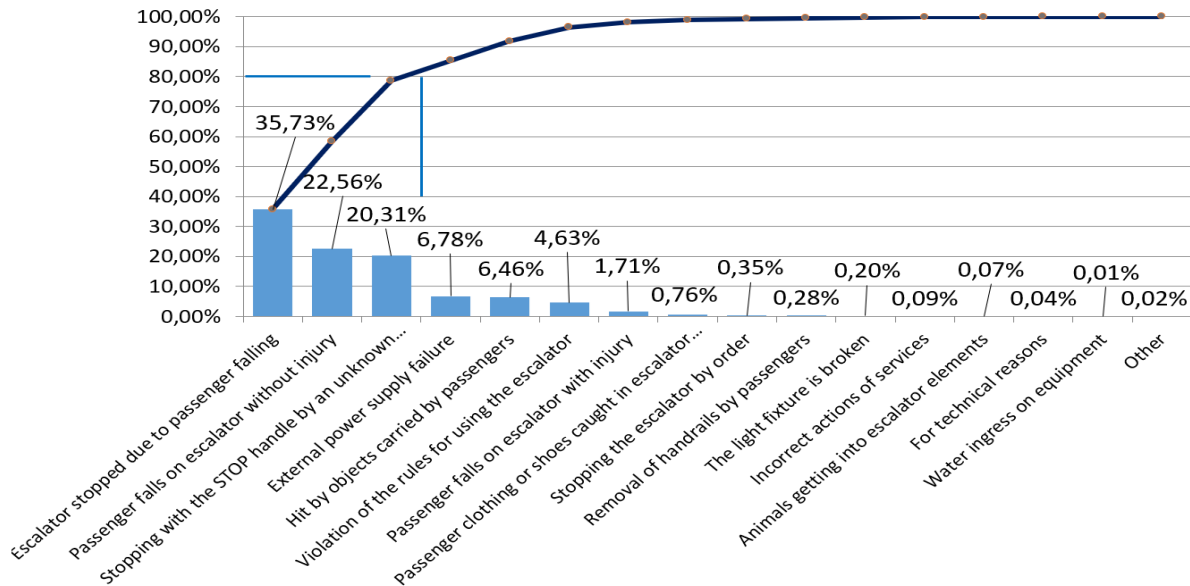


Fig. 4. Pareto for escalator safety violations.

A similar analysis is carried out for vertical transport equipment, the analysis of safety discrepancies of which shows a similar structure of the causes of the influence of the human factor and technical failures and malfunctions.

For the risks of identified causes, it is recommended to develop an information monitoring and control system that implements the shutdown of the escalator upon detection of detector readings corresponding to the appearance of key markers of safety violations by their types. Such markers include violations of geometry, movement, location of elements, occurrence of indicator loads, vibrations, failures of electrical equipment, violations of rules by passengers, identified by artificial intelligence based on the analysis of the video data stream.

Diagnostics of non-conformities for such equipment using electronic monitoring systems can transmit data to a specially developed unified information dispatching system, which, in both manual and automated control modes, identifies a hazardous situation, categorizes it, makes a decision to block it and call workers responsible for technical maintenance of the equipment to eliminate the consequences of safety violations.

The general scheme of the proposed automated dispatch control of continuous and vertical transport facilities for the purpose of ensuring passenger safety is shown in Fig. 5.

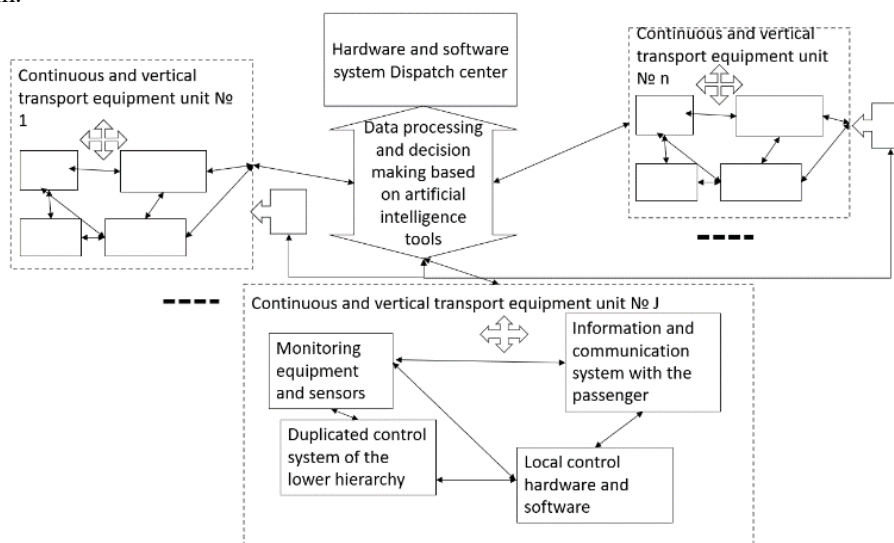


Fig. 5. Scheme of automated dispatch control of continuous and vertical transport facilities.

IV. CONCLUSIONS

Proposals for the development of intelligent systems to ensure the safety of equipment for passengers at key transport infrastructure facilities include:

- Identification of technical reliability and safety deficiencies based on statistical analysis of incidents and using reliability theory and risk management tools.
- Definition and development of detection markers to identify and classify reliability and safety non-compliance situations.
- Develop hardware for detection and data collection that generate an online data stream for complete identification of a transport situation.
- Select and develop tools and algorithms for automated intelligent data flow analysis and making current decisions on blocking and eliminating a dangerous situation.
- Develop the architecture and configuration of a hardware and software complex for ensuring technical safety at a transport infrastructure facility.
- Conduct testing, analysis and revision of information system releases taking into account new data to improve safety at a transport facility.

The conducted studies have shown the effectiveness of using statistical and cause-and-effect analysis tools to identify inconsistencies in the reliability of technical systems, for the further development of the concept, configuration and basic algorithms of intelligent information systems that can improve safety at the facilities of the transport infrastructure of the metropolis.

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Development of Digital Twin Models of Transport Facilities Taking into Account their Life Cycle

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Abstract— The article is devoted to the problem of ensuring the efficiency of cargo transportation logistics management based on information technologies. It is proposed to use digital twins as an important tool for monitoring and managing key transport objects using rolling stock as an example. The life cycle of a transport object and the life cycle of an intelligent software product are analyzed. The cyclic model of development and implementation of a software product is studied, which requires the use of change management and configuration management methods over a long period of supporting the operation of a transport object. The configuration of an information system containing digital twins and their management is proposed. An example of the operation of a refrigerated container as a complex cargo transportation object requiring monitoring and optimal online management in the process of providing a transport service is considered. Proposals are given for the development of digital twins of transport objects in order to improve the efficiency of logistics activities of transport companies.

Keywords— *transport logistics, complex technical system, information system, digital model, digital twin, life cycle, software product, quality management.*

I. INTRODUCTION

When creating information systems for supporting and managing processes, equipment and objects in complex

production, transport and other technical facilities, one of the effective tools is the development of digital twin models that allow consolidating a set of individual data on objects, tracking their dynamics, monitoring, analyzing and developing optimal solutions for managing objects to solve assigned tasks [1, 2].

The development of digital twins of technical objects for the purpose of their optimal management is especially effective in cases where it is necessary to carry out online support and control of processes on the one hand, as well as to process large amounts of accumulated information and implement information continuity throughout the entire life cycle of a technical object [3, 4].

The movement of an object through the stages of its life cycle is accompanied by the formation, accumulation and transfer of information, allowing for the effective planning, design, production, operation, modernization and disposal of the object.

The life cycle of a technical object, the information processes accompanying it and the digital model are shown in Fig. 1.

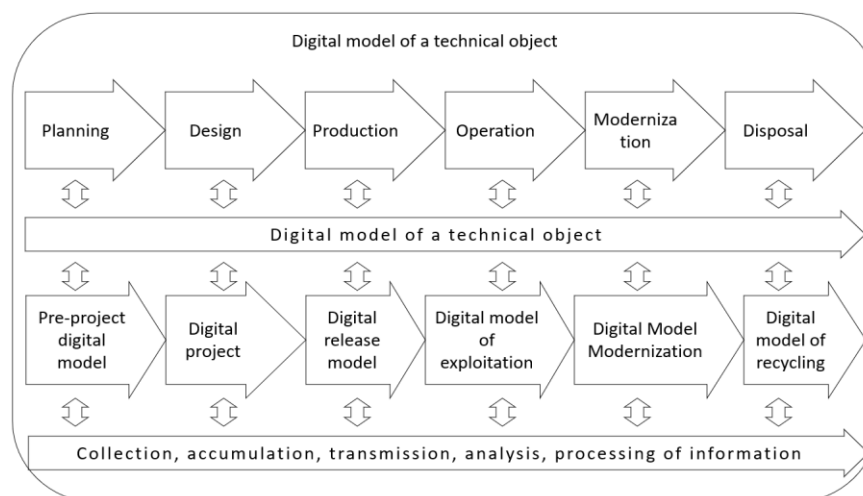


Fig. 1. Scheme of the life cycle of a technical object.

II. OBJECTS AND METHODS OF RESEARCH

It should be noted that the digital model integrated into the general information system and all the software under consideration follows its own life cycle of an intelligent information product and, during the maintenance of a

technical object, is refined and developed in accordance with information system design technologies.

The development, release and implementation of the software product is carried out on the basis of the following diagram, presented in Fig. 2.

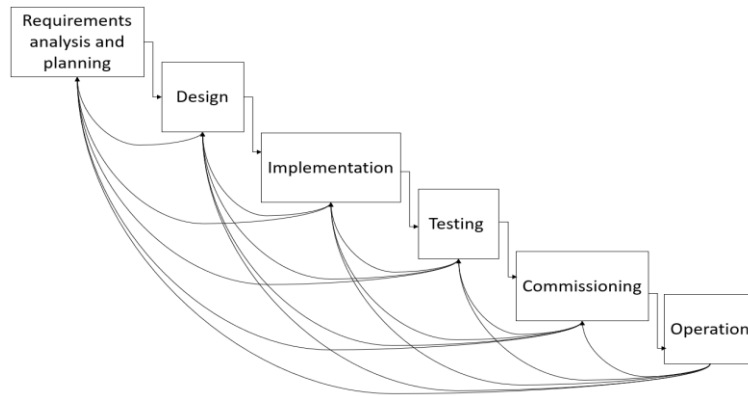


Fig. 2. Scheme of development and implementation of the software product.

Let's consider a transport and logistics company as an example of a complex technical system. A transport company can gain competitive advantages and successfully conduct business based on the best possible satisfaction of customer needs in terms of transportation quality.

Therefore, increasing control and optimizing the manageability of the transportation process becomes an important task for a transport company. One of the important objects of transport management is rolling stock, and in the case of multimodal transportation - a transport cargo container.

The importance of improving flexible transportation management leads to the need to develop digital twin models for freight cars and containers, especially in the case of transportation with maintenance of a given climatic regime.

However, since the service life of rolling stock and containers can be several decades, the corresponding software implementing a digital twin for such objects requires the use of a cyclical development model during its operation.

The scheme of cyclical development of the information product of the digital twin is presented in Fig. 3.

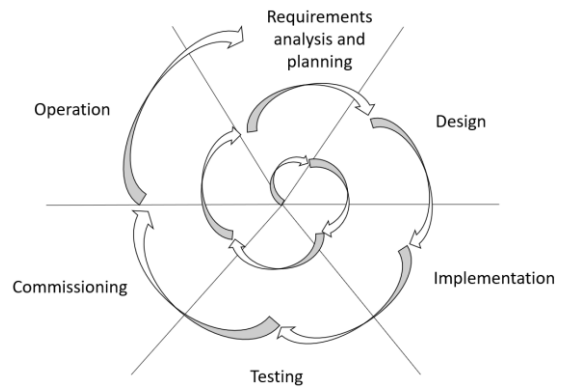


Fig. 3. Scheme of cyclical development of the information product.

An information product using a digital twin model requires additional operational testing, testing, refinement and adjustment, as well as its development during long-term use to take into account new transportation requirements and new states of the transport system [5, 6]. For this purpose, at each turn of the cyclic model of the software product, the methodology for managing incidents, problems, releases and configuration is constantly applied.

The scheme for managing the development of a software product during operation is shown in Fig. 4.

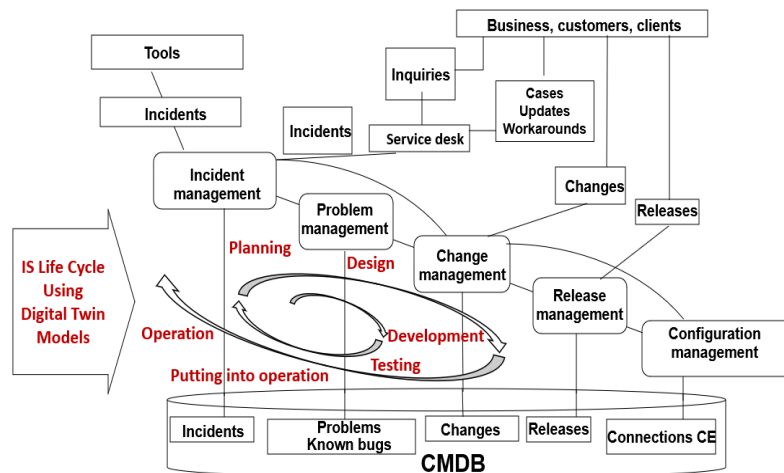


Fig. 4. Software product development management scheme.

III. RESULTS AND DISCUSSION

To develop an information system for a transport company containing digital twin models, it is necessary to take into account a number of additional functions and systems that should be included in its architecture.

To ensure work with digital twins of rolling stock, the following systems should be further developed:

- A system for accumulating, processing and managing data on digital model objects (freight rolling stock, refrigerated cars and containers. Data should be supplemented, consolidated and transmitted throughout all stages of the life cycle of a transport object).
- Systems for monitoring and controlling the parameters of online operation of transport facilities (location, speed, characteristics of the climatic condition inside the container, characteristics of the external environment, characteristics of the operation of the equipment).
- Information security systems.

- Systems for diagnosing the quality of transport services provided to clients.
- Systems for analyzing the transport risks of cargo transportation.
- Systems for technical audit of processes and equipment.
- Document management and data flow registration system.
- Intelligent decision support system for transportation management.
- Optimization system for transportation parameters and processes.
- Consolidation and management system for data and parameters of digital models.

The architecture of the proposed information system is presented in Fig. 5.

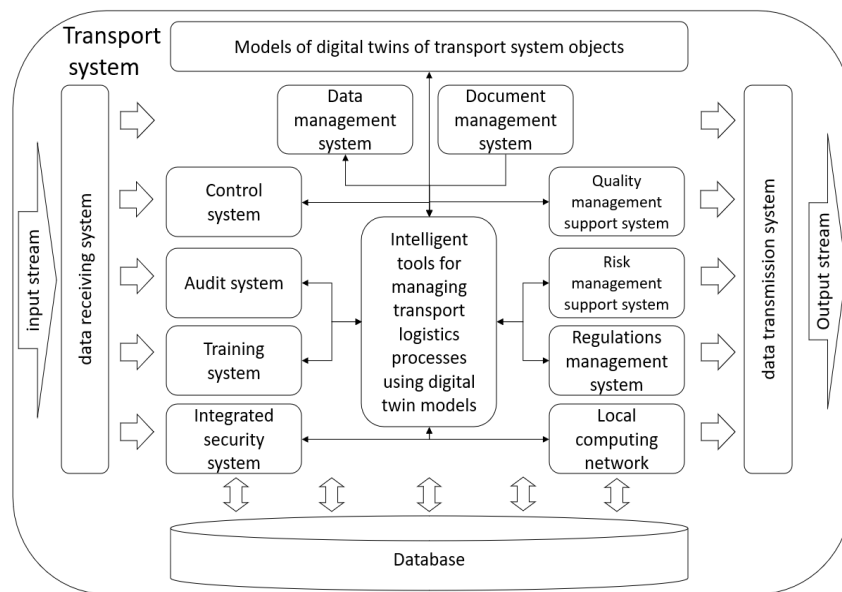


Fig. 5. General architecture of the information system of a logistics transport company.

Let's look at an example of developing a digital twin of a refrigerated container.

The composition of digital information about a refrigerated container includes:

- Data about its model and geometry, including a 3D model.
- Data about the container equipment and its characteristics.
- Online data about the container's climate conditions (temperatures at control points, humidity, ventilation flows).
- Online data about the container's geographic location, its speed, condition and status.

- Data about operation (failures, repairs, equipment replacement).

To implement control, this online data must be transmitted by wireless means of communication and formed in a digital model of the container as part of the carrier's information system [7, 8].

To manage transportation modes, functions for making decisions on control in an automated or manual mode must be provided, implemented wirelessly.

Fig. 6 shows a diagram of a refrigerated container's equipment.

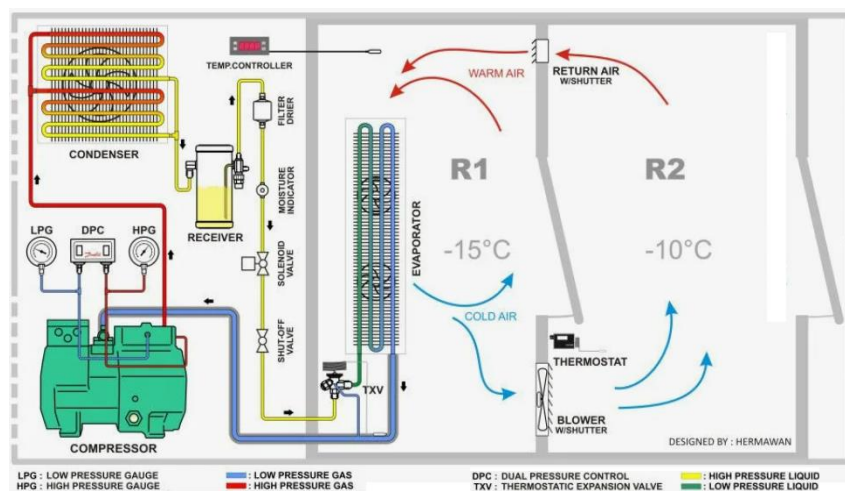


Fig. 6. General diagram of a refrigerated container's equipment.

Online management and climate control of a refrigerated container during transportation, as well as control of its transshipment in transport hubs during multimodal transportation, ensures an increase in the quality of container transportation services for clients of a logistics company.

Data on the history of container operation, its equipment, its structural condition and failures, its current maintenance and major repairs, technical audits of its condition and suitability for use, can be stored and analyzed during the period of operation to make a decision on its further use or decommissioning.

IV. CONCLUSIONS

The following approaches and methodological recommendations are proposed for developing models of digital twins of transport system objects:

- Analyze the life cycle of a digitalization object, its planned life and operational features.
- Analyze the set and structure of information sufficient for monitoring and managing transportation in order to improve the quality of the freight transportation service.
- Analyze the composition and structure of accumulation, processing and transmission of data throughout the life cycle of a digitalization object.
- Analyze the life cycle of the digital modeling software product being developed, provide mechanisms for its development while supporting the life cycle of a transport object.
- Select and justify the used intelligent information tools for decision-making on optimal management of freight transportation using digital twins.
- Develop the concept and architecture of an information system for a logistics company using digital models of transport objects.

The methods of development and application of intelligent information systems using digital twins of transport facilities considered in the work will allow logistics companies to improve the efficiency of business processes and the quality of cargo transportation services, which will

create the basis for increasing the company's competitiveness in the multimodal cargo transportation market.

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Development of Digital Models of Maintenance Processes at Wagon Repair Plants

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Abstract—The article is devoted to the problem of ensuring the quality of maintenance and repair of the park of railway passenger wagons based on the management of production processes using information technology. To increase the efficiency of maintenance, the method of digital modeling of the processes of operation and repair of passenger railway wagons, based on the monitoring of their current state, collecting and accumulating information on basic technical parameters, is used. To improve the quality of the wagon repair, it is proposed to integrate the results of the check and diagnosis into a single digital product (digital wagon passport), which allows you to control the implementation of all technological repair operations.

Keywords— *quality of maintenance, railway passenger wagons, information technology, digital modeling, monitoring, non-destructive testing.*

I. INTRODUCTION

Organizing efficient rolling stock repair is an important tool for ensuring the reliability and quality of rail transportation. This requires the development and implementation of modern technical and information solutions that allow generating and analyzing data on technological operations to improve the accuracy, productivity, and quality of repair production processes [1, 2].

The main and systemic task facing the repair complex is to improve the quality of wagons repairs, since existing technologies often do not allow for prompt and accurate detection of faults that appear during operation.

Analysis and solution of these problems, which can increase repair potential and provide more accurate diagnostics of malfunctions in the operation of wagon equipment, can be carried out using new innovative methods of digital modeling of repair processes [3, 4].

With the development of technological solutions and the introduction of automation, the issue of transferring the results of tests of repaired units and parts, carried out using technological and testing equipment, arises. This issue can be

resolved by developing "digital twins" of wagons repairs and combining them into a single automated system - a "digital passport" for the repair of passenger wagons, which will increase the efficiency of the repair process itself, as well as optimize the repair time of units and parts [5, 6].

It should be noted that the recording and recording of the beginning and end of the wagon repair, the stages of the repair, the condition of its units and parts, allow tracking and, if necessary, adjusting the final and intermediate repair time without deteriorating the quality of the repair, identifying "bottlenecks" and technological shortcomings, which will ultimately allow for significant optimization of the time the wagon is taken out of service.

The process of integrating automation into the planned repair of a locomotive-hauled passenger wagon is the transfer of all intermediate and final (acceptance) measurement and diagnostic results into a single "digital twin" of the wagon repair, together with the primary (upon receipt for repair) and final (acceptance upon release) inspections of the wagon.

For this purpose, production areas and workshops are equipped with diagnostic equipment, "digital" keys, special markings (barcodes, QR codes) are applied to the units and parts being repaired, and the final test of the wagon is carried out with an imitation of its movement. These mechanisms make it possible to significantly improve the quality of repairs and reduce the number of wagons malfunctions that occur during the inter-repair period.

To apply digital modeling of the operation and repair processes of railway wagons, it is necessary to model their entire life cycle on the balance sheet of the carrier organization from the moment of purchase to disposal [7, 8]. Such a digital model is integrated into the unified information system of the transport organization, which also includes digital models of other objects involved in ensuring transportation.

The diagram of the digital model of the wagon as part of the company's information system is shown in Fig. 1.

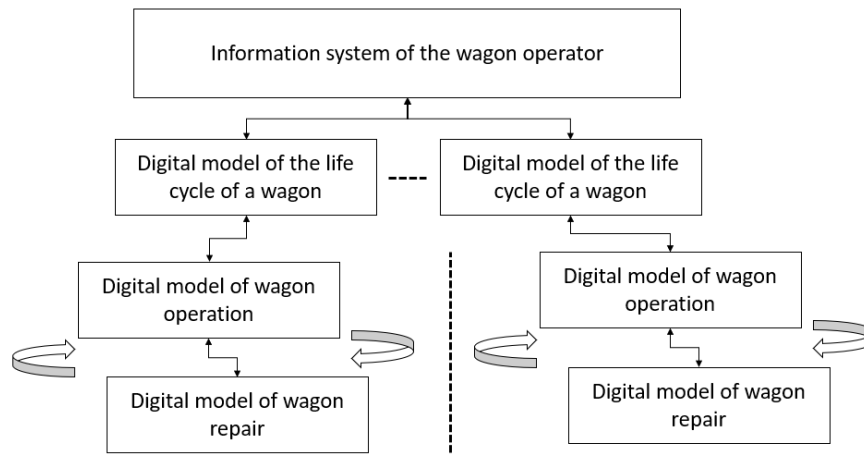


Fig. 1. Scheme of a digital model of a wagon integrated into the information system of a transport enterprise

Let us consider the tasks of ensuring the implementation of technological operations during the scheduled repair of wagons.

The existing technology for carrying out scheduled repairs of a passenger wagon is shown in Fig. 2.

II. OBJECTS AND METHODS OF RESEARCH

Let's consider digital support for the process of repairing a passenger railway wagon.

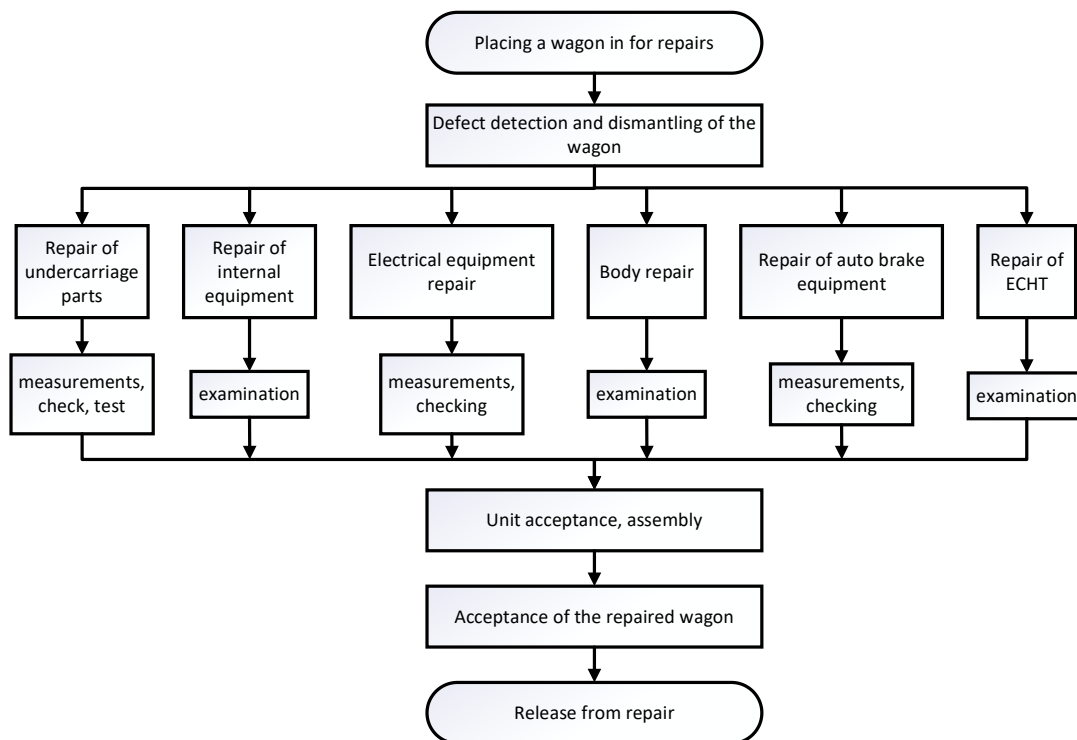


Fig. 2. Scheme of scheduled repair of a passenger wagon

Each wagon arriving for repair undergoes a commission acceptance, where the completeness and the volume of necessary additional and routine repairs are recorded.

After inspection and decision on acceptance of the wagon for repair, the equipment is dismantled and sent to specialized workshops (bogies, wheel pairs, generator, batteries, elements of the environmentally friendly toilet complex, etc.).

Next, after the necessary routine repair work is carried out, testing and unit-by-unit acceptance of the equipment is carried out. If positive results are obtained, the repaired units and parts are placed back on the wagon.

Then, after the wagon is assembled, its final acceptance is carried out and, if comments or malfunctions are detected, the wagon is sent for their elimination or replacement of poorly repaired units (parts) with new or previously repaired ones.

However, the existing technology does not involve the transfer of the received information to an automated database for the accumulation of statistics, and subsequent analysis to identify "bottlenecks" or make decisions on the need to change technological operations during repairs.

Therefore, automation and the use of "digital twin" technology will allow accumulating and processing a large amount of information on the technical maintenance of a

wagon during its life cycle. Based on data analysis, it is possible to optimize the management of wagon repairs, control the actual workload of workshops and sections, which allows increasing the productivity and efficiency of production processes.

To solve this problem, a mechanism for collecting and transmitting the results of acceptance, operational and final

diagnostics and inspection after repair of parts, units and systems of the wagon is proposed. A "digital passport" of the wagon is formed, confirming the performance of all technological operations at each stage of its repair and acceptance. The scheme for forming a "digital passport" of wagon repair is shown in Fig. 3.

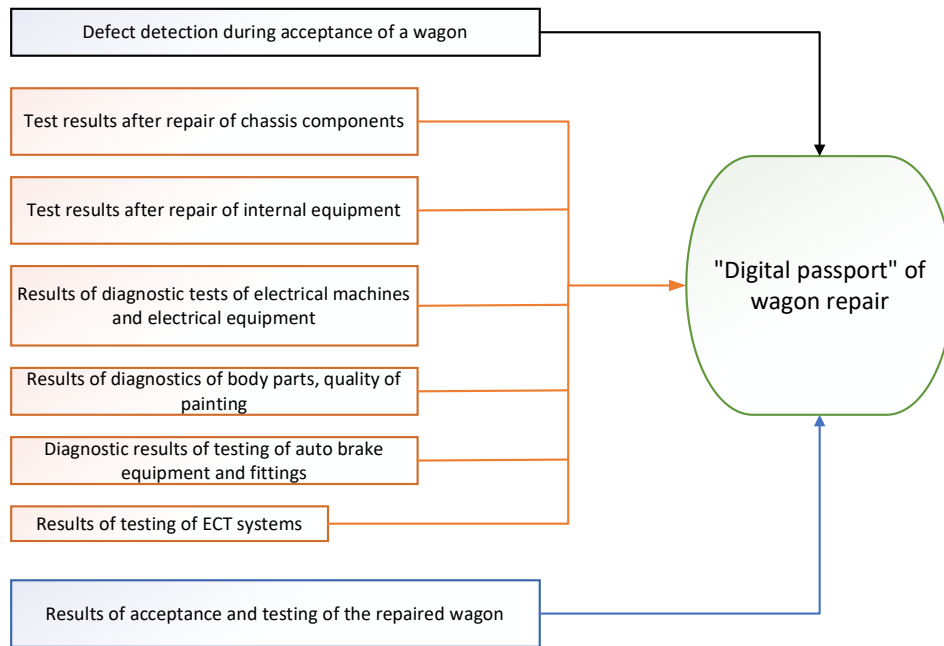


Fig. 3. Scheme of the "digital passport" of the wagon repair

III. RESULTS AND DISCUSSION

When a wagon is received for repair at a wagon repair plant, a "digital passport" of wagon repair is created, where all mandatory and additional repair work is recorded.

If the condition of the wagon satisfies the capabilities of the repair plant to carry out its scheduled repair, the "digital passport" is sent to the relevant sections and workshops in the form of a technical assignment for repair.

If the wagon is dismantled, there is significant damage, then, by agreement with the wagon owner, additional work is determined, as well as the time for their implementation, which is also recorded in the "digital passport".

If the wagon cannot be repaired for technical reasons, it is returned to the operator or sent for restoration work to a wagon repair plant that has the necessary equipment and personnel with the appropriate qualifications.

The time of forced downtime required for diagnostics is recorded in the "digital passport" at the repair plant and the wagon is listed in the status of "waiting for acceptance of the wagon for repair after the incoming inspection". If the wagon is not accepted for repair and sent to another station (by decision of the wagon owner), information about the work performed and the diagnostic results are saved in its "digital passport".

After the wagon is accepted for repair, it is disassembled and the dismantled units and equipment are transferred to specialized workshops. At this stage, the time spent on dismantling the units and parts of the wagon, their transportation to the repair site, or to the warehouse of working products (if the repair is carried out in a specialized

organization or center) for its replacement with spare parts located in the working stock is taken into account.

At this stage, production operations for transporting dismantled equipment to production sites are taken into account, allowing for the establishment of possible technological or logistical costs.

After the units and parts arrive at the production areas, they are inspected and diagnosed, and possible hidden defects or wear are identified. The results of the defect detection and necessary additional repair operations are entered into the "digital passport" of the wagon. Based on the results of the repair, in accordance with the requirements of the regulatory and technological documentation, re-diagnostics of the repaired units are carried out.

Thus, after the repair of the wheel sets, the operability of the axle boxes is checked on a vibration diagnostic stand. After the repair of the gearbox, simulating running-in tests are carried out with the control of a number of technical characteristics, based on the results of which test reports with a conclusion on their serviceability are automatically generated.

The received test reports are transferred to the "digital passport" of the wagon repair and are a mandatory element for the final acceptance of the wagon after its scheduled repair.

After completing the repair operations, the workers of the production areas install the equipment back on the wagon, where the period from the release of finished products to their final installation is recorded. At this stage, it is possible to establish logistics costs, as well as "overstocking" or

"deficit" of the working fund of finished spare parts and units in the workshops to ensure an optimal wagon repair process.

Upon completion of all technological operations for repair of previously dismantled units and parts, the site managers make notes in the corresponding sections of the "digital passport" of the wagon repair and the stage of final acceptance of the wagon begins. Before the commission acceptance, the wagon undergoes running tests with imitation of movement and checking of the operability of all equipment.

During the final acceptance, specialists confirm the facts of the technological operations performed by means of a full-scale inspection using specialized diagnostic equipment.

If any discrepancies are detected, the wagon is sent for correction of the violations. The results of the final acceptance inspection are entered into the automated system.

Upon final acceptance and recording of the final diagnostic protocols in the "digital passport", the function of issuing a notification of the final acceptance of the wagon and its release from repair becomes active.

IV. CONCLUSIONS

The implementation of the "digital passport" technology for the repair of a locomotive-hauled passenger wagon allows:

- To record discrepancies or significant comments when accepting a wagon for repair.
- To establish the periods of equipment being under repair, the time spent on disassembling and subsequent assembly of the wagon.
- To determine technological, technical, logistical and regulatory discrepancies that require their solution or adjustment.
- To establish the actual technological need for the working stock of spare parts and materials in the production areas of the structural unit.
- To increase efficiency and productivity to ensure the rhythmic release of passenger wagons from scheduled repairs.

Thus, the implementation of digital technologies at railway transport enterprises plays one of the key roles in ensuring the efficiency of its production units.

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The Logistics Risk Management in a Digital Technological Enterprise Integrated Management System

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Abstract— The article is devoted to the theoretical substantiation and practical application of logistics risk management methods in an integrated management system of a digital high-technology enterprise. In the theoretical analysis, the authors studied the structure of a digital high-technology enterprise, characterized the features of the integrated management system of this enterprise. The factors have been identified and ways to reduce risks in managing a digital high-technology enterprise have been identified. In conclusion, the authors propose a decision-making algorithm for managing the logistical risks of a digital high-technology enterprise.

Keywords— digitalization, risk, logistic, high-tech enterprises integrate management system, algorithm.

I. INTRODUCTION

The urgency of the problem of logistics risk management is currently beyond doubt. Risk becomes an integral element of socio-economic relations and becomes an organic part of the strategy and tactics of socio-economic policy of enterprises. Regardless of the reasons for the risk in logistics activities, it is natural for every company to reduce possible losses associated with the implementation of risk. That is why there is a problem of logistics risk management, i.e. risk management. For any organization, no matter what field of activity it participates in, risk management means identifying, analyzing, and managing those risks that may threaten the organization's assets and profitability.

The search for effective business strategies that give organizations competitive advantages in the context of globalized market processes has allowed economic science and practice [1, 3, 7, etc.] to develop and adapt a number of approaches where production is considered as an element of the value chain. Along with production, financial, corporate, innovation management and marketing, an organizational strategy for integrating production and operations, human resource management, financial management and asset management, focused on continuous balancing and optimization of enterprise resources through a specialized integrated application software package, the ERP (Enterprise Resource Planning) concept, is becoming increasingly relevant [2, 10]. The implementation of an ERP system is

considered a de facto prerequisite for a public company, and since the late 1990s, ERP systems, initially implemented only by industrial enterprises, have been operated by most large organizations, regardless of country, form of ownership, or industry. A characteristic feature of the ERP strategy is the fundamental approach to using a single transactional system for the vast majority of operations and business processes of the organization, regardless of the functional and territorial separation of their locations and passage, the obligation to combine all operations into a single database for subsequent processing and obtaining balanced plans in real time.

Applicability in various industries imposes on ERP systems, on the one hand, requirements for versatility, on the other hand, support for extensibility by industry specifics. The main large systems include ready-made specialized modules and extensions for various industries. Specialized ERP solutions are known for machine-building and manufacturing industries, extractive industries, retail, distribution, banks, financial organizations and insurance companies, telecommunications companies, energy companies, organizations in the public administration sector, education, medicine and other industries.

Developments for solving the tasks of automated management support using so-called ERP systems (Enterprise resources planning – Enterprise resource Management) are currently being conducted quite actively. At the same time, a number of local tasks have been sufficiently worked out.

The issues of supply chain management in the formation of global flows (of materials, goods, and services), as well as the integration and coordination of suppliers, manufacturers, logistics providers, and consumers are considered by I.O. Protsenko, O.V. Butch, and others [3, 5]. Supply chain planning and execution in real time (Supply Chain Management) (Bauroks D., Kloss D., et al.) [1]. However, these researchers do not aim to provide comprehensive management of enterprise resources, limiting the task only to "programming" the supply of parts.

O.N. Melnikov [6] considers the development of a new management system that uses the corporate creative energy of all participants in business processes as an economic tool

for shaping modern market relations, taking into account the synthesis of all possible high-tech and logistical ways to achieve this goal. The risk structure of the logistics system and its specifics are considered by P.P. Goncharov, N.E. Garms [4]

In addition, economics has developed programs for managing a company's relationships with its customers, partners, dealers, and the outside world in general (CRM - Customer Relationship Management). In fact, it is a tool for automating the work of marketing, sales and customer service departments. Plus a set of additional services in the form of corporate portals, call centers, online help desks for clients, corporate knowledge bases, etc.

Human Resource Management (HRM) is currently implemented using highly intelligent applications, the tasks of which are recruiting, managing and effectively using the potential of all employees of the enterprise. KM – Knowledge Management systems were created to accumulate corporate knowledge and were used for internal consumption. Until recently, all these programs were relatively self-sufficient, meaning they practically dispensed with ERP systems [12].

Currently, there is a need to use a fully functional unified company resource management system (ERP system), which can provide huge advantages to an enterprise in organizing effective company management, increasing the speed of response to changes in the external environment, and improving the quality of customer service. The purpose of the study is to identify, theoretically substantiate and experimentally test logistics risk management methods in an integrated management system of a digital high-tech enterprise.

In accordance with the purpose of the work, the following research objectives are defined:

1. To study the structure of a digital high-tech enterprise

2. To characterize the features of the integrated management system of this enterprise
3. To propose a decision-making algorithm for managing the logistical risks of a digital high-tech enterprise.

To date, a lot of research has been conducted in the field of assessing the logistical risks of industrial enterprises and their management capabilities, but no effective mechanism has been created that includes comprehensive risk analysis (for example, using modern ERP systems), allowing possible risks to be diagnosed at any stage of the logistics chain and eliminated in a timely and effective manner.

The theoretical and methodological basis of the work was research, fundamental and applied developments of domestic and foreign scientists in the field of economic theory, theory of inventory management, methodology of modeling and forecasting, methodological approaches to the management of certain types of logistics activities.

In the course of the research, the methods of operations research, system, logistic and economic analysis were used.

II. THE STRUCTURE OF A DIGITAL HIGH-TECH ENTERPRISE

A digital high-tech enterprise is an organization that uses data and results from various kinds of reports and analytical indicators obtained from internal or external sources of the company in its business processes when making decisions. Information technology in such a company becomes an integral part and is necessary for the restructuring of the entire business, production, relationships with customers and contractors, and the formation of company management methods that integrate processes throughout the enterprise.

The introduction of digital technologies in the enterprise leads to a change in the business model. This is due to a change in the principles of enterprise management (Table 1), the digital transformation of organizational functions and the optimization of business operations.

TABLE I. PRINCIPLES OF A DIGITAL HIGH-TECH ENTERPRISE

№ pp	Principles	Contents
1.	An architectural approach.	When implementing any changes, an understandable and transparent enterprise model is needed, in which structural and hierarchical relationships can be easily traced. The architectural approach to the reform of the management system allows the company to have a transparent model that describes all the relationships and interactions of the elements. This helps to monitor all changes in time and see their consequences.
2.	Data-driven business process management, where data is tracked and processed across all business functions.	All decisions in a digital enterprise are made based on data analysis. Customers or partners connected to the enterprise electronically can receive personalized offers by accurately identifying their needs as a result of data analysis. Also, such work allows you to optimize many processes in the company.
3.	Support for internal communications.	Digital technologies make it possible to organize an effective exchange of information within the company. This strengthens the communication system within the enterprise and helps to respond more efficiently and faster when solving problems.
4	Adaptability.	In order to quickly adapt to market changes and new environmental requirements, it is important for the company to continuously carry out organizational changes. Therefore, it is necessary to regularly increase the competencies of staff in the field of project management.
5.	The involvement of the manager in the implementation of business innovations.	A digital enterprise involves vertical integration of processes (from product development to logistics and maintenance during operation), while horizontal integration encompasses suppliers, consumers, and partners. Managers at different levels in the company need to be actively involved in these processes.
6	Ecosystem approach.	When an enterprise operates within the framework of an external motivating environment that unites different competencies of participants in the implementation of innovations.

III. THE INTEGRATED MANAGEMENT SYSTEM OF A DIGITAL HIGH-TECH ENTERPRISE

To assess the risks of a digital enterprise, we will reveal its management technology. The management is based on the Integrated Management System (IMS). This system ensures consistency and structures the company's actions in accordance with international standards [5]. The classical integrated management system is based on simultaneous compliance with several international standards:

1. Quality management system (regulated by GOST R ISO 9001-2015 (ISO 9001:2015) standard);
2. Environmental management system (regulated by GOST R ISO 14001-2016 (ISO 14001:2015) standard);

3. Occupational safety and health management system GOST R 54934 -2012 (OHSAS 18001:2007)).

However, when building an IMS of a digital high-tech enterprise, we believe it is mandatory to use the requirements of the information security management system GOST R ISO/IEC 27001-2006.

In accordance with the PDCA methodology, we will build an integrated management system for a digital high-tech enterprise. Certification of an integrated management system combines the advantages of each of its management systems. It ensures the fulfillment of requirements for improving the level of quality, ecology, information and professional security. Thus, the IMS of a digital high-tech enterprise is based on the "Plan - do- check - act" (PDCA) methodology [8]. The main requirements are presented in Table 2.

TABLE II. PDCA METHODOLOGY OF THE INTEGRATED MANAGEMENT SYSTEM OF A DIGITAL HIGH-TECH ENTERPRISE

	Quality Management System GOST R ISO 9001-2015 (ISO 9001:2015)	Environmental Management System GOST R ISO 14001- 2016 (ISO 14001:2015)	Occupational safety and Health Management System GOST R 54934 -2012 (OHSAS 18001:2007)	Information Security Management Systems GOST R ISO/IEC 27001-2021
plan	Develop the objectives of the system and its processes, as well as identify the resources needed to achieve results in accordance with customer requirements and organizational policies, identify and consider risks and opportunities.	development of environmental objectives and processes necessary to achieve results consistent with the organization's environmental policy.	setting goals and developing the processes necessary to achieve results in accordance with the organization's Oh&S policy	Develop ISMS policies, objectives, processes, and procedures related to risk management and information security improvement to achieve results consistent with the organization's overall policies and objectives
do	doing what was planned	implementation of processes as planned	process implementation;	implementation and application of the information security policy, management measures, processes and procedures of the ISMS
check	monitoring and (where applicable) measuring processes, products, and services against policies, goals, requirements, and planned actions, and communicating results	Monitoring and measuring processes in relation to the implementation of the environmental policy, including the commitments contained therein, environmental objectives and performance criteria, as well as reporting on the results.	monitoring and measuring processes to assess their compliance with Oh&S policy, objectives, legal and other requirements, and reporting the results	evaluating, including, if possible, quantifying, the effectiveness of processes in relation to policy requirements, security objectives, and practical experience of the ISMS, and informing senior management of the results for subsequent analysis.
act	taking measures to improve performance to the extent necessary	taking actions for continuous improvement	adoption and implementation of decisions on continuous improvement of performance indicators in the field of Oh&S	carrying out corrective and preventive actions based on the results of internal audit or other relevant information, and analysis by management in order to achieve continuous improvement of the ISMS

Thus, at the stage of input data and system integration, various information systems are digitally integrated, namely ERP (Enterprise Resource Planning), CRM (Customer Relationship Management) and SCM (Supply Chain Management), which forms a unified information environment and ensures interaction between company departments and improves coordination using big data technologies (BigData).

The "Plan" stage builds the modeling process and the use of software for modeling.

Each of the management system standards included in the structure of the integrated management system of a digital high-tech enterprise provides for a risk assessment.

Logistical risk is the possibility of such an event occurring after a decision has been made, as a result of which an enterprise completely or partially loses its material resources, goods, products, and incurs additional logistical costs.

The company's logistics risks can be divided into external and internal (Fig. 1). The subject of an integrated management system of a digital high-tech enterprise, unlike a traditional transport company, is the management of both internal and external logistics risks.

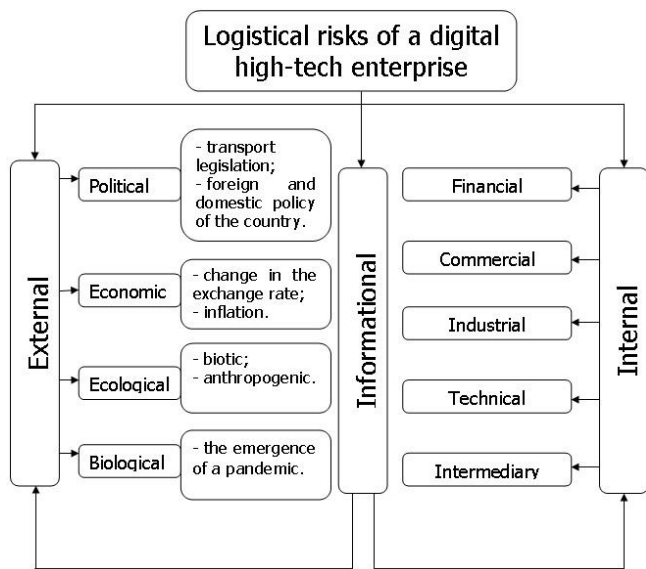


Fig. 1. Classification of logistical risks in the management system of a digital high-tech enterprise

The risk management strategy applies a number of rules based on which a particular risk management technique and solution option are selected. The main of these rules are the following: maximum winnings; optimal combination of winnings and the amount of risk; optimal probability of outcome.

Maximum gain means that out of the possible solutions containing risk, the one that provides the maximum result (income, profit, etc.) is chosen with minimal and acceptable risk for the entrepreneur.

Since, in practice, more profitable options are also more risky, of all the solutions that provide an acceptable risk for an entrepreneur, the one with the highest ratio of income and loss (loss) is chosen, which is the essence of the rule of optimal combination of gain and risk.

The essence of the optimal outcome probability rule is that of all the options that provide an acceptable probability for an entrepreneur to obtain a positive result, the one with the maximum gain is selected [10].

Dynamism is a mandatory attribute of any sphere of production and economic activity. The dynamics are based on streaming processes. They are the subject of logistics studies. The concept of "flow", for example, material, commodity, cargo, information, money, energy, passenger, etc., is found constantly and everywhere. At the same time, logistics alone considers this concept not as an abstract form of movement of any materialized objects, but as a specific object that arises and develops according to certain laws, has characteristic parameters and requires the same struggle for quality as material resources.

The logistic approach to the organization of both transport and transportation processes, as well as the entire supply, production, distribution and sales system, gives tremendous results in practice. Not only the final, but also the intermediate indicators of production and economic activity are accompanied by a synergistic effect that allows for maximum progress under any circumstances. In the context of market turbulence, this is of great importance for any enterprise at the local level, as well as for macroeconomic phenomena in general.

IV. DECISION-MAKING ALGORITHM FOR MANAGING LOGISTICS RISKS OF A DIGITAL HIGH-TECH ENTERPRISE

The integrated management system of a digital high-tech enterprise should meet the key directions of digitalization of the industry, namely the introduction of digitalization of business processes, the use of digital technologies and ensuring cybersecurity.

In order to fill in the structure of a digital high-tech enterprise and determine the possibilities of using an integrated management system, it is necessary to conduct a comparative analysis of the enterprise of the old management paradigm and the management paradigm of a digital high-tech enterprise.

The decision-making algorithm for logistics risk management in traditional management is shown in figure 2.

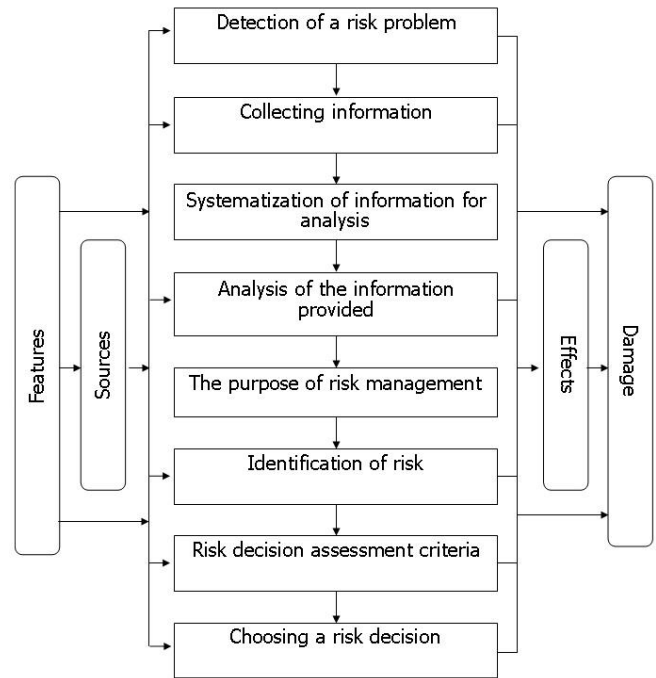


Fig. 2. The decision-making algorithm for logistics risk management in traditional management

Risk management becomes relevant after the discovery of a risk problem. In this case, the results of risk analysis and modeling should be used. In relation to risk, as a probable failure, the following management actions are possible: prevention, reduction, compensation for damage, absorption.

If the problem is well structured based on substantive and statistical information, then it is possible to apply programmed solutions. Then the methodological features of various types of management are reflected in the development of algorithms for preparing and making risk decisions.

The development of special algorithms for making risk decisions can ensure the necessary level of quality of organizational decisions and reduce the role of subjective factors. It is very important that this can speed up the risk management process.

A specific decision-making algorithm can be developed for each of the typical risk problems for an organization. At the same time [14], it seems possible to develop an algorithm for making risk decisions for various types of management.

The decision-making algorithm for managing logistics risks of a high-tech enterprise is shown in figure 3.

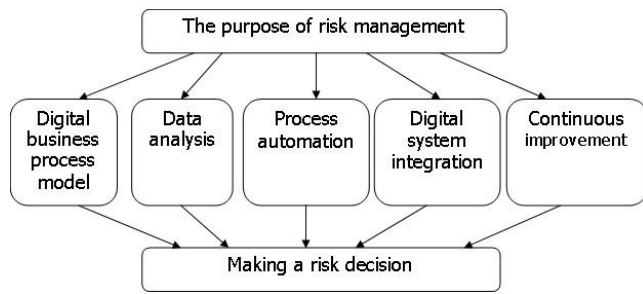


Fig. 3. The decision-making algorithm for managing logistics risks of a high-tech enterprise

Let's look at the main stages in more detail.

1. Process modeling: Using software tools for modeling business processes, such as BPMN (Business Process Model and Notation), allows you to visualize existing processes and see potential bottlenecks. Digital models contribute to a better understanding of the interaction between different departments and processes, as well as help assess the impact of anticipated changes.

2. Data Analysis: The collection and analysis of large amounts of data using Business Intelligence (BI) and Database Management Systems (DBMS) tools provide valuable information to determine the effectiveness of processes. Machine learning and Data Mining tools can identify hidden patterns and suggest ways to improve.

3. Process Automation: Robotic process automation (RPA) is one of the key technologies that allows you to speed up routine operations, reduce errors and free up employees for more complex tasks. The automatic execution of standardized tasks increases the productivity and efficiency of the company.

4. Digital System Integration: The digital integration of various information systems such as ERP (Enterprise Resource Planning), CRM (Customer Relationship Management) and SCM (Supply Chain Management) provides a unified information environment that improves coordination and interaction between departments.

5. Continuous improvement: Digital technologies facilitate the application of lean manufacturing and Kaizen concepts aimed at continuous process improvement. Feedback collection systems, KPIs monitoring and analytical tools allow you to monitor the effectiveness of implemented changes in real time and immediately adjust the development strategy.

Examples of innovative technologies for optimization:

- Artificial intelligence and machine learning make it possible to predict demand, optimize inventory, and improve customer service.;
- Blockchain can serve to create transparent and reliable supply chains, its use, for example, in the activities of transport logistics enterprises makes it possible to simplify routing and dispatching services [15];
- The Internet of Things promotes smart automation of production and real-time data collection from devices for monitoring and process management. For example, the Industrial Internet of Things (IIoT) connects industrial equipment (machine tools, conveyors, etc.) directly to the

cloud, which allows employees to monitor the entire production process in real time in a virtual environment and, if necessary, make any changes.

The impact of external factors is difficult to assess, however, the digital integration of various information systems such as ERP (Enterprise Resource Planning), CRM (Customer Relationship Management) and SCM (Supply Chain Management) forms a unified information environment and provides, using artificial intelligence and big data technologies (BigData), an architectural database of identified risks and their consequences. sources. Under such circumstances, the magnitude of information logistical risks increases, which affect external and internal risk factors.

V. CONCLUSION

In general, the logistics risk management system of a high-tech enterprise should be based on a number of principles [6]:

- measurability of the input risk parameters;
- the reliability of the basic data used for the required calculations;
- step-by-step approach to risk management;
- implementation of software products that take into account the specifics of enterprises;
- development and use of company-specific indicators to identify internal and external risks.

This risk management system is continuously linked to the transportation management process. The practical significance of the results lies in the fact that the developed algorithm for managing logistical risks at digital high-tech enterprises can be used to develop a strategy for the development of their logistics activities. Undoubtedly, the implementation of the risk management model is impossible without the development and implementation of our own unique software products that simplify risk assessment.

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IT Strategy of the International Container Cargo Transportation Control System

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Abstract— The article is devoted to the analysis of the components and tasks of the ERP IT-system in the context of the development of the control system for container transportation. In the theoretical analysis, the authors present recommendations for improving ERP systems necessary for the high-quality and effective development of modern IT strategies of the enterprise. The main and additional modules included in the structural composition of the components of the high-tech multi-level ERP system used by domestic and foreign carriers are defined. The existing trends in the reengineering of IT ecosystems are analyzed, with subsequent optimization of the structural core and main components of the ERP system based on the "Low-code" platform. The authors give practical recommendations for the structural improvement of the components and tasks solved at various levels of ERP systems in order to increase the efficiency of using digital technologies for monitoring international container transportation.

Keywords— system, IT-strategy, ERP systems, control, cargo transportation, digital technology.

I. INTRODUCTION

The active transition to the digital space and the intensive introduction of digital and smart technologies in all areas of the Russian economy suggest that in the near future, in accordance with the trend of digital transformation of industry [18, 19], a radical change in business processes and technological processes will be carried out, including in the control system for international container transportation. The prerequisites for this lie in the concept of forming a VUCA world (unstable, rapidly changing, uncertain and complex), in which the speed of digital technology adoption surpasses the introduction of any other innovative developments to business. A person is subject to strict requirements for the assimilation of exponentially increasing amounts of information.

An IT strategy is a conceptual plan for the development of information technology, coordinated with a business strategy, the implementation of which will ensure that the development of information technology is aligned with the long-term prospects that the business is building. Proper and, most importantly, targeted use and effective financial investments in the development of information technology in the organization. Users show results more effectively. Coordinated actions of senior management and IT staff in solving business problems. The development of information technologies, taking into account the territorial scale of the business and its diversification. The main strategic objective of information

technology is to support the achievement of long-term goals and operational business objectives through the successful implementation of technical projects for the introduction of information systems and technologies that ensure the achievement of competitive advantages and economic benefits, which is one of the main missions and objectives for business. Information support for business processes carried out at the required quality level, and whether it is possible to increase the quality of the performed process better. Improving the organization of IT services in terms of efficiency, productivity and cost optimization.

The thesis about the need to implement an IT strategy (technologies, resources, etc.) is the words of the author of the book "What the numbers say" Tom Davenport, the founder of the theory of reengineering: "What is really important is to achieve conceptual unity in such areas as the strategic goal of the company, the chosen business model, the information necessary for its functioning, and finally, the technologies that provide the required information."

If we take a quote from Pavel Alferov and a representative of foreign experts in the field of business analysis, then we can conclude that an IT strategy is not only necessary, but also an additional auxiliary tool that will provide accurate answers to a number of questions that the organization might not even know about, namely: How much to spend on IT. How to convince a business of this. What processes may change. What needs to be done for changes. How to coordinate information technology and business. By its very nature, an IT strategy is part of the overall strategy of an organization, and that at one time is part of the enterprise architecture. As already mentioned, although the IT strategy is part of the overall strategy and is essentially only a part, it is not a dependent part, but a fundamental one. [20] So at the present time, the missions and goals are determined by the IT strategy, which should take into account:

1. The result of an analysis of the current activities of the organization.
2. IT goals must meet business requirements for information technology.
3. The overall vision of information technology (architecture of information products, system management levers, technology selection and justification, etc.).
4. Cost estimates for the implementation of the IT strategy.

In this regard, the topic of research on the strategy of the control system of international freight container transportation is very relevant. The main purpose of the work is to propose a digital strategy for the international container transportation control system.

To achieve the goal, it is proposed to solve the following tasks:

- to study the digital maturity of the transport and logistics industry and the criteria for its assessment in the implementation of international container transportation;
- to evaluate alternatives to developing an IT strategy for a transport company;
- to propose ways to improve the international container transportation control system.

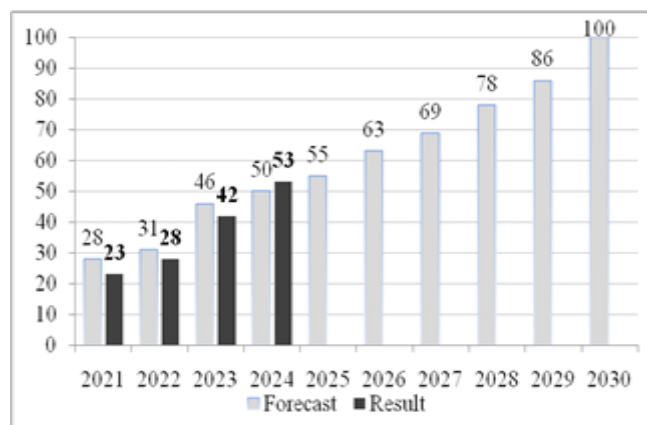


Fig. 1. Forecast values and the achieved result of the dynamics of the digital maturity of the industry, %

Of the eight indicators of the digital maturity of the industry, five characterize the implementation of the IT strategy of the international container transportation control system. (Table I).

II. ANALYSIS OF THE DIGITAL MATURITY OF THE TRANSPORT SERVICES MARKET IN INTERNATIONAL CONTAINER TRANSPORTATION

The digital maturity of transport and logistics has been monitored since 2021. (Fig. 1).

TABLE I. INDICATORS OF THE DIGITAL MATURITY OF THE TRANSPORT INDUSTRY

An indicator of digital maturity	The criterion in the IT strategy	2021	2024	Deviations from the 2024 forecast	Forecast 2030
1. The proportion of airports using biometric passenger identification data to pass through the transport security zone and board a flight in cities with a population of one million		6	32	2,4%	60
2. The share of government information resources available online through data storefronts	+	35	40	-5,7%	80
3. The share of freight transportation by rail, processed electronically using the services of JSC "Russian Railways"	+	85	88	0,4%	90
4. The share of passenger transportation by rail, processed electronically using the services of JSC "Russian Railways"		69	82	3%	90
5. The share of electronic ship documents issued by the captains of seaports of the Russian Federation	+	0	20	-9,9%	50
6. The share of traffic flows in the transportation of goods coordinated using artificial intelligence	+	0	23	1,1%	60
7. The share of certificates issued based on the results of electronic applications from applicants for the state service of issuing certificates to persons from among the specialists of civil aviation personnel from the total number of applications		0	51	3,1%	60
8. The proportion of newly commissioned and reconstructed sections of the backbone highway network equipped with infrastructure that provides interaction with automated vehicles operated in unmanned mode	+	0	34	-8%	85

The main transport modules involved in international container transportation are rail and sea transport.

Currently, the railway transport segment is demonstrating high results in the implementation of IT strategies. Thus, the share of freight shipments processed electronically using the services of Russian Railways reached 85% in 2024.

For maritime transport, a significant increase in efficiency is possible due to the digitalization of document management. Based on this, the proportion of electronic ship documents issued by the captains of seaports of the Russian Federation has been established as an indicator of digital maturity. By 2030, it should make up at least half of all ship's documents.

III. OPTIONS FOR DEVELOPING AN IT STRATEGY

The field of information technology is quite young and specific. Clearly established approaches are not fully formulated in it. This also applies to the development of an IT strategy. Nevertheless, the following options can be conditionally distinguished [11]:

- lack of an IT strategy;
- planning in terms of software and technical resources;
- copying trends;
- planning in the context of key business success factors;

- defining the goals and objectives of an IT strategy through a business strategy;
- alignment of business and IT strategy;
- specialized industry approaches;
- unusual and exotic approaches.

There is no point in talking about the last two options in detail, but the rest should be described in more detail.

The first option is the simplest and most unpromising. Nevertheless, quite a lot of companies exist without IT strategies. And they exist relatively successfully. But if their management had taken the development of information technology more seriously, the results of their organizational activities would have been better.

Planning in terms of software and hardware is the second most popular option, after the lack of strategic planning as such. There is an emphasis on increasing the productivity of information technology in the company. But there is no common goal setting and understanding of what role they should play in business development.

Copying trends means that management is generally aware of the importance of information technology for the organization, but is not well versed in the specifics. Therefore, he tries to either do like everyone else, or implement the latest developments. This approach often turns into a waste of budget.

The key success factors are the main strategic goals and capabilities of the organization, which affect its ultimate effectiveness and determine its mission [1]. This option implies that informatization and automation should primarily be applied to those business processes that directly affect key factors. However, if an organization is large enough, then each of the top managers can understand its business strategy in their own way.

Building an IT strategy based on the goals and objectives of a business strategy may well be used in cases where the IT department plays a supportive role for the main business processes. But in the context of digitalization, the IT department should not be a technical support service. In this case, it is much more logical not just to adjust the provisions of the IT strategy to the goals and objectives of the business strategy. Similarly, a business strategy should be formed and updated based on the potential and real capabilities of the available information technology tools. [16]

The sixth option (alignment) implies a balance between two extremes: risk and opportunity. Despite the great difficulties associated with alignment, it is this option that is most often considered the most preferable. Nevertheless, there is a rather interesting study that refutes this thesis [13]. Its authors have made an attempt to trace how the level of consistency of business and IT strategy affects the effectiveness of the IT department. As a result, they mathematically proved the existence of a negative correlation between these two variables. In other words, the more effort and resources are spent on balancing these two types of strategies, the less effective the IT department is.

Each of the options has its drawbacks. Especially when an organization is developing an IT strategy for the first time. It may take several unsuccessful attempts to create at least a viable strategic plan. And this is a waste of time, money and, most importantly, the trust of the management. If a hard-won

IT strategy doesn't pay off, they may simply not give you a second chance.

The main disadvantage of each option is the lack of standardization. In general terms, each of them is applicable in any field of activity. But in detail, even the simplest option (planning in terms of software and hardware) will have its own sequence of actions in each specific case. A universal approach is needed. It should include a general concept (which will form the basis for developing an IT strategy) and elements for analysis. Both should be applicable in most average departments.

There is an ISO/IEC 33020 standard for evaluating IT processes. This document has a Russian equivalent, GOST R ISO / IEC 33020-2017 [8, 9]. The basis of his concept is a five-level scale for assessing the level of process capability. There is an analogy with the SMM methodology (Capability Maturity Model) [1].

However, the CMM evaluates the maturity of the software development processes. GOST considers any processes, not only related to information technology, and determines their level of effectiveness. It is important to understand that maturity and process efficiency are not the same thing. Maturity shows the level of manageability and predictability of the process. The extent to which it is controlled [17]. Efficiency implies the level of usefulness that information technology creates for business at rational and controlled costs and risks [3].

GOST 33020 provides tools for evaluation. As already mentioned, the key element of this toolkit is a scale of levels, where each level corresponds to properties with a set of parameters for evaluating the process (Table II).

TABLE II. LEVELS OF EFFICIENCY OF THE IT-STRATEGY PROCESS [1]

The level of efficiency of the process	Level Properties
Incomplete process	An unfinished process that failed to achieve its intended result
The implemented process	The result has been achieved, but it is unlikely to be repeated. The effectiveness of the process
Managed process	The process has achieved a result and can be repeated. 2.1. Performance management; 2.2. Results Management
The established process	The process is not just repeated, it is documented. 3.1. Process Definition; 3.2. Process Deployment
A predictable process	The process is carried out within the established limits to achieve the planned results. 4.1. Quantitative analysis of the process; 4.2. Quantitative control of the process
Optimizing process	The process is continuously improving, adapting to changing conditions. 5.1. Innovativeness of the process; 5.2. Implementation of process innovations

Evaluating effectiveness based on clearly defined properties minimizes the negative impact of the human factor caused by the choice of data. The interpretation of the results obtained will also be unambiguous, since it is carried out using a scale and an established rule: the level is reached only if all the properties on it are fulfilled by at least 50%. In general, the GOST methodology makes it possible to assess the level of efficiency of IT processes without making a decision at all.

IV. DIRECTIONS FOR IMPROVING THE IT STRATEGY OF THE INTERNATIONAL CONTAINER TRANSPORTATION CONTROL SYSTEM

Business automation has made it possible to digitize all available information, introduce new methods of analysis and information exchange, and combine different types of data. The results of the automated analysis contributed to a more competent allocation of production capacities and the subsequent adoption of optimal decisions for business development. The methodology of doing business using various automated enterprise resource management programs was called ERP, and the software used for this purpose was called an ERP system. That is, all computer programs designed for accounting, personnel management, etc., are parts of the ERP system, while CRM (customer relationship management system) also refers to ERP and translates as "customer relationship management system" [4, 6].

The ERP strategy of many domestic high-tech enterprises is monolithic and focused on a single supplier. This often becomes a limiting factor for the IT strategy as a whole. Therefore, it is necessary to bring your ERP and IT strategy in line with modern requirements and lay a suitable foundation for the successful development of your company's digital business. One of the most important goals of the modern IT strategy is to create an updated ERP core with a basic set of functions focused on both process standardization and data and process support for other business activities of the enterprise. The ERP system development strategy is one of the decisive factors for the success of the IT strategy as a whole and should take into account the following main recommendations [2]: - to conduct a multicomponent analysis of the core of the ERP system, and identify the components that will support and ensure the effective implementation of the chosen digital business strategy; - create a two-tier management model that will ensure effective management of both accounting systems and systems for implementing unique business processes and innovations; - pay due attention to the core competencies necessary for the success of an IT strategy in today's world - leadership in change, talent development, integration strategy and strategic vendor management; - explore not only traditional ERP-system vendors. This is especially important when searching for systems for the implementation of new business processes that ensure the competitiveness of the enterprise and allow for innovation. The updated ERP system combines the main and additional modules in its architecture (Fig. 2.) [9].

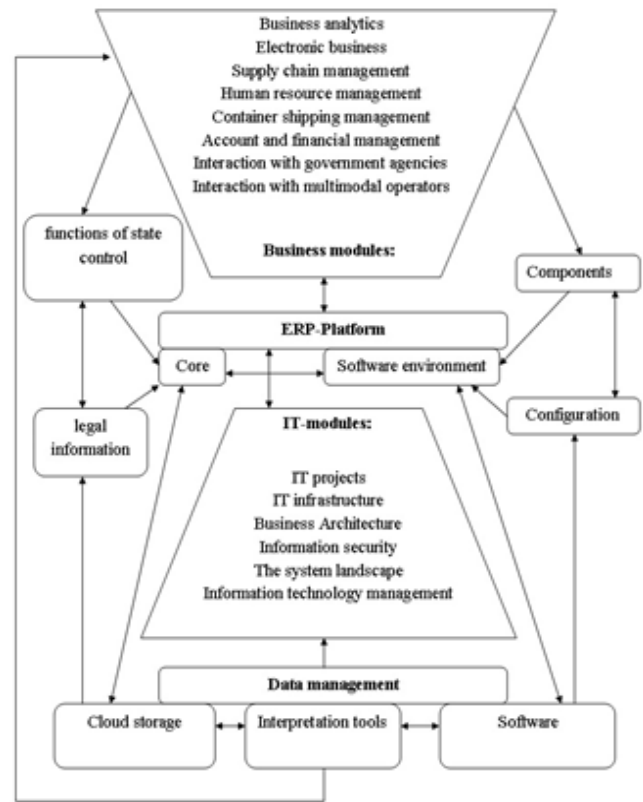


Fig. 2. The structure of the modern ERP-system of the international container transportation control

Risk Platform. The platform includes: a core, i.e. a software environment in which work will be performed, for which you can write some add-ons and components; basic functionality, a list of reference books and functions without which no enterprise can operate.

Fig. 3. Data management. Database, including data storage and interpretation methods. This category includes data storage on a server, software for working with databases (for example, SQL), tools for interpreting and processing data and sending it to software modules[7].

Modules. Components that connect to the platform as needed. They all work with a single database and apply basic functionality.

The transition to the updated ERP system is due to a fundamental change in the six main elements directly related to business processes (Table III) [5].

TABLE III. ANALYSIS OF COMPONENT CHANGES DURING THE TRANSITION TO AN UPDATED ERP-SYSTEM

Components	Classic ERP-system	Updated ERP-system
Role	Improvement of production processes within the enterprise	Active participation in the creation of added value. The necessary structural framework for the development of e-commerce components
Scope of use	Production and sale	Absolutely all segments of the company
Functions	Production, sales, optimization of financial processes	Cross-industry, industry-specific and special processes
Process	Internal, hidden	Explicit, using the top level
Architecture	Monolithic, closed, Web-enabled	Multicomponent, open, based on industrial Internet technology
Date	They are developed and applied directly within the enterprise itself.	Data is freely published and provided both inside and outside the company.

The introduction of additional functions into the ERP system will allow any company to keep pace with the changing market situation around them. The heads of high-

tech enterprises are wondering what opportunities the ERP system provides for the further development of digital business, the implementation of which required considerable

budgets and resources. Traditional ERP approaches do not provide an appropriate foundation for digital business, so it is important to create an effective IT strategy and an IT environment that meets the current pace of digital business development. Many transportation companies continue to choose ERP systems and a single supplier to create a single solution to achieve all the goals stated in the company's strategy. Thus, the IT strategy is too strongly tied to the ERP vendor.

Thus, business users use third-party cloud solutions in parallel with corporate ERP. Such a spontaneous decomposition of the enterprise's IT ecosystem is destructive, as it excludes the possibility of managing end-to-end business processes and collecting data arising during transportation, which can potentially be used to manage it and predict events. Therefore, it is necessary to take the spontaneous decomposition of the IT ecosystem under close control and ensure the necessary flexibility.

The IT ecosystem will be assembled through a combination of cloud and on-premises solutions, depending on the enterprise strategy. Such a strategy for building IT ecosystems will be jointly laid and managed by business representatives, and will become the cornerstone for all initiatives aimed at building a digital business. The depth of reengineering of the enterprise's IT system will directly depend on the company's strategy and other objective factors. For example, without using the traditional accounting functions of such systems, it is impossible to ensure the operation of complex business processes of the financial service, personnel management and operational support. So the accounting systems in the classical form will not disappear, but will change [3, 6]. The goal of the modern IT strategy is to create an updated ERP core with a basic set of functions focused on both process standardization and data and process support for other commercial activities of a transportation company. Such a management model of IT systems is called a two-tier one [2].

Level 1: Application of a set of standardized processes aimed at implementing the functionality of the accounting system.

Level 2: Using a multi-component system to comprehensively support various innovations.

The two-tier IT system management model provides full-fledged and effective management of both accounting systems and systems for implementing unique business processes and innovations. The updated ERP core will have the attributes of an accounting system and, as expected, will slowly change and adapt. At the same time, the core will ensure the reliable functioning of immutable processes, and prevent unnecessary operational costs. The management of revenue-generating processes will be transferred from accounting systems to systems designed to support innovation.

V. CONCLUSION

The monolithic IT architecture does not satisfy the regularly transformed business processes of the organization, and part of the functionality of the information system is implemented in the form of its own development or external services, often located in the cloud. The main issue that needs to be addressed at the IT level now is the integration of various applications within end-to-end business processes, which is why RPA technology is now available, which allows you to "glue" internal and external applications, as

well as microservice architecture, which allows you to move away from monolithic applications in the IT architecture. The introduction of Robotic Automation (RPA) technologies increases the efficiency of staff, reducing the need to perform routine processes. Implementations in dozens of Russian companies and organizations have demonstrated that the use of technology significantly reduces business costs and risks, improving the quality of services provided, process manageability, and staff efficiency.

The transition of some IT applications to the cloud is an inevitable process, and integration with our own internal IT applications will become increasingly difficult with a large number of changes in business processes. Therefore, in the long-term planning horizon, we can expect the emergence of ecosystems in corporate IT application markets, where integration between ecosystem participants will be pre-configured. This trend has been around in the B2C market for a long time, large platforms have created ecosystems within which some of the integration problems have already been solved. Multibillion-dollar budgets for ERP applications are becoming a thing of the past, competition in the IT market and the emergence of industry solutions will enable global players to gain an advantage by creating standard solutions for various processes and transferring them to the cloud.

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Digital Transformation of Sales Processes: Development of IT Strategies and Leading Marketing in the Digital Economy

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Abstract — This material is devoted to the development and implementation of IT strategies for the digital transformation of sales processes and proactive marketing in the digital economy. It discusses the application of a wide range of IT solutions and the cataloging of IT services for the full lifecycle of sales processes. In today's rapidly changing market environment, companies need to adapt to new technologies and evolving consumer preferences. The article discusses key aspects, including the analysis of current sales processes, including the evaluation of existing methods and the identification of problem areas that hinder effective product sales; the definition of SMART goals and the use of modern technologies, such as CRM systems, marketing automation systems, and analytical tools, to improve customer engagement and optimize processes; and the development of proactive approaches in anticipatory marketing, which allow for anticipating customer needs and adapting to market trends using big data.

Keywords— *digital transformation, sales processes, it strategy, advanced marketing, digital economy, sales processes, process classification, information technology, crm systems, big data, artificial intelligence, blockchain, social networks, marketplaces, e-commerce, search engines, omnichannel approach, real-time analytics, personalization, catalogization of it services.*

I. INTRODUCTION

In today's rapidly evolving digital economy, companies are faced with the need to adapt and implement new approaches in their sales and marketing processes. Developing an effective IT strategy and implementing proactive marketing are crucial steps for businesses to thrive in this era. The overall vision of digital transformation and proactive marketing leads us to the realization that only flexible, adaptive, and proactive business approaches can guarantee success in an ever-changing market [3, 12]. Sustainable business growth can only be achieved through the adoption of advanced technologies and a conscious focus on customer needs. Attention to these aspects will undoubtedly shape the future of organizations in the digital age.

II. CLASSIFICATION AND CHARACTERISTICS OF PRODUCT SALES PROCESSES

The classification of product sales processes and their characteristics help companies to manage all stages more effectively, from preparation to results analysis [14]. Applying effective strategies at each stage contributes to increased competitiveness and improved customer experience (table 1).

TABLE I. CLASSIFICATION AND CHARACTERISTICS OF PRODUCT SALES PROCESSES

Category	Process type	Description	Specifications
1. Preparation for sales	Market research	Market and consumer analysis to identify needs and preferences.	Using analytical tools to assess market trends.
	Strategy development	Defining sales goals, strategies, and tactics.	Setting clear and measurable goals based on the target audience profile.
2. Product promotion	Marketing campaigns	Development and implementation of advertising campaigns to draw attention to the product.	Use of various channels: digital, traditional, social media, and PR.
	Establishing a brand	Creating a positive product image through various communication channels.	Maintaining consistency in all materials and communications, and creating a value proposition.
3. Demand generation	Search and qualification	Attracting and selecting potential customers who are interested in making a purchase.	Using CRM systems to manage customer data and assess their readiness to purchase.

Category	Process type	Description	Specifications
4. Establishing contact	Primary interaction	Establishing contact with customers and building trust.	Using various forms of communication, such as phone calls, face-to-face meetings, and messaging apps.
	Product Presentation	Overview of product features and demo display, and answers to questions.	Use of videos, webinars, and demonstration samples.
5. The result of the transaction	Conclusion of an agreement	Execution of the transaction, signing of contracts.	Support for electronic signatures and digital contracts to speed up the process.
	Terms of payment and delivery	Defining and negotiating the terms of the transaction: payment and delivery.	Integration with online payment systems and logistics companies.
6. Order fulfillment	Logistics and delivery	Organizing the process of delivering goods to customers.	Route optimization and delivery status tracking using technology.
	Customer service	Customer support after purchase: answering questions and processing complaints.	Service through various channels: phone, chat, and email.
7. Evaluation of results	Analysis of the results	Evaluating the effectiveness of all sales processes through data management.	Using KPIs to measure success, including sales volume, customer satisfaction, and profitability.
	Feedback	Collecting feedback and suggestions from customers to improve the product and service.	Use SurveyMonkey, Google Forms, and other tools to collect and analyze feedback.

The creation of a sales process strategy includes the following steps:

1. Definition of the digital economy and its impact on business.
2. The importance of an effective sales strategy in the context of digitalization.
3. The goals and structure of the report.
1. The analysis of the current situation is characterized by the following components:
 - 1) assessment of current sales processes: analysis of existing methods and technologies;
 - 2) market analysis: research of market trends and consumer preferences in the digital economy;
 - 3) identification of the target audience: creation of a customer profile based on data.
2. Defining the goals of the sales strategy:
 - 1) main goals: increasing efficiency, increasing sales volumes, and improving customer experience;
 - 2) SMART goals: specific, measurable, achievable, relevant, and time-bound;
 - 3) KPIs for evaluating the success of the strategy: defining key performance indicators.
3. Developing strategic directions:
 - 1) integrating digital technologies;
 - 2) implementing CRM systems for managing customer relationships.

III. IT CLASSIFICATION FOR THE FULL LIFE CYCLE STAGES OF SALES PROCESSES AND THEIR CHARACTERISTICS

Information technology (IT) plays a key role in all stages of the sales process lifecycle. Proper classification and understanding of these technologies enable companies to optimize their operations, improve efficiency, and enhance

the customer experience. In this report, we will explore the different types of IT used in each stage of the sales process lifecycle and their characteristics [7].

1. Preparatory stage

At this stage, companies analyze the market, competition, and target audience.

- Analytical tools:
- Feature: Allow you to collect and analyze data about consumers and markets.
- Examples: Google Analytics, Tableau, Power BI.

Project management systems:

- Feature: Help you organize and manage tasks within your team.
- Examples: Asana, Trello, Jira.

2. Lead generation

At this stage, companies attract potential customers and collect information about them.

- Marketing automation:
- Feature: Automates customer acquisition processes and marketing campaign management.
- Examples: HubSpot, Marketo.

CRM systems:

- Feature: Stores customer data and manages interactions, which helps in lead qualification.
- Examples: Salesforce, Zoho CRM.

3. Establishing contact

This step involves direct interaction with the customer.

- Communication tools:
- Characteristics: Provide tools for online calls, video calls, and text communication.
- Examples: Zoom, Microsoft Teams, Slack.

Email marketing platforms:

- Characteristics: For creating and sending newsletters and notifications.
- Examples: Mailchimp, Constant Contact.

4. Product presentation

This step involves demonstrating the product and its benefits.

- Demo tools:
- Feature: Allow you to visually present the product and its functionality.
- Examples: Loom, DemoBuilder.

Web tools:

- Feature: Used to create attractive product pages.
- Examples: WordPress, Wix.

5. Closing the deal

This is where the formalization of the deal takes place.

- Electronic signature platforms:
- Feature: Provide legal force to signed documents in digital format.
- Examples: DocuSign, Adobe Sign.
- Tools for creating commercial offers:
- Feature: Facilitate the creation and sending of commercial offers to customers.
- Examples: PandaDoc, Proposify.

6. Order fulfillment

At this stage, logistics and order fulfillment are organized.

- Supply Chain Management (SCM) systems:
- Feature: Optimizes supply and inventory management processes.
- Examples: SAP SCM, Oracle SCM Cloud.

Order tracking platforms:

- Feature: Allows customers to track order status and receive notifications.
- Examples: ShipStation, Aftership.

7. Evaluation and analysis of results

At this stage, the performed operations are analyzed and the results are evaluated.

- Analytical tools:
- Characteristics: Used to track KPIs and analyze sales data.
- Examples: Google Analytics, QlikView.

Tools for collecting feedback:

- Characteristics: Allow to collect customer opinions about products and services.
- Examples: SurveyMonkey, Typeform.

The classification of IT for the stages of the full life cycle of sales processes allows you to understand which

technologies to use to improve the efficiency and quality of customer interaction [8]. Using the right tools at each stage It contributes to the implementation of sales strategies and significantly improves the customer experience, which in turn leads to business growth.

The use of social media, marketplaces, the internet, and the search for new systems in sales processes [15].

Modern technologies and platforms have radically changed the approach to sales processes for products and services [10]. Social media, marketplaces, the internet, and search engines have become important tools for attracting customers, increasing sales, and improving competitiveness. Let's explore how these tools are used in sales processes and the benefits they provide.

1. The use of social media

Social media has become an important channel for promoting products and services, as well as for interacting with customers.

- Product promotion: Social media platforms (such as Facebook, Instagram, Twitter, and LinkedIn) allow companies to directly engage with customers by sharing information about products, promotions, and news.

- Advertising and targeting: Social advertising platforms allow you to target your audience based on their interests, behavior, and demographics, which can help improve the effectiveness of your advertising campaigns.

- Customer feedback and service: Social media platforms provide a way to get real-time feedback from your customers and provide real-time support.

2. Using marketplaces

Marketplaces are platforms where sellers and buyers can interact with each other, which can create new opportunities for businesses.

- Access to a wide audience: Platforms like Amazon, eBay, Wildberries, and Ozon allow sellers to enter new markets by providing access to millions of potential customers.

- Simplified processes: Marketplaces often offer ready-made solutions for sales management, logistics, and payment processing, making it easier for small and medium-sized businesses to sell their products.

- Reputation and trust: Sellers can use reviews and ratings to build trust with customers, which is often a deciding factor when choosing a product.

3. The use of the internet

The internet serves as the foundation for most digital marketing and sales strategies.

- E-commerce: Creating online stores allows companies to sell products directly to end consumers. Platforms like Shopify and WooCommerce make this accessible even for small businesses.

- Content marketing: Companies can use blogs, videos, and other content formats to attract attention and create valuable content that improves the visibility of products and services.

- Data management and analytics: The internet provides many tools for collecting and analyzing customer data, which

helps to improve sales strategies and tailor offerings to user needs.

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4. Search engine optimization

Search engines play an important role in how customers find information about products and services.

- **Search Engine Optimization (SEO):** Optimizing websites for search engines allows businesses to rank highly in search results, increasing organic traffic and visibility.

- **Search engine advertising (PPC):** Advertising on search engines such as Google Ads allows companies to attract customers based on keywords related to their products or services.

- **Search query analysis:** Studying the terms users use to search helps companies tailor their offerings and marketing to better meet customer needs.

The use of social media, marketplaces, the internet, and search engines in sales processes is a powerful set of tools that can significantly improve business outcomes [5]. These technologies allow companies to not only reach new customers, but also build strong relationships with them, increasing loyalty and satisfaction [4]. However, successful implementation of these strategies requires careful planning and continuous performance analysis to achieve sustainable growth and competitive advantages.

The use of blockchain, big data, and artificial intelligence in sales processes [16].

Modern technologies are radically changing approaches to business processes, including the sales of products and services [1]. Blockchain, big data, and artificial intelligence (AI) are becoming important tools for improving efficiency, optimizing operations, and enhancing customer experiences. Let's explore how each of these technologies is being applied in sales processes [6].

1. Application of blockchain technologies

Blockchain is a distributed and secure database that ensures transparency and security of transactions.

- **Supply chain management:** Blockchain allows for the tracking of every transaction in the supply chain, ensuring

transparency and reducing fraud. This enables businesses to better control the origin of their products.

- **Streamlining processes:** Smart contracts can automate the execution of transaction conditions, speeding up processes and reducing the likelihood of errors. Payments can be made automatically when certain conditions are met.

- **Increased trust:** The use of blockchain helps to increase customer trust, as all transactions are publicly available and immutable, making it easy to verify the origin and quality of products.

2. The application of big data

Big data (Big Data) is a voluminous information that companies can use to gain valuable insights.

- **Customer behavior analysis:** Companies use big data to study consumer behavior, which allows them to better understand preferences and create personalized offers.

- **Price optimization:** Analyzing historical sales and demand data helps determine the optimal prices for products, which can increase profitability.

- **Demand forecasting:** Using algorithms to analyze past data allows for predicting future customer needs, which helps in inventory management and minimizing losses.

3. Applications of Artificial Intelligence

Artificial Intelligence (AI) has a wide range of applications, particularly in the fields of automation and data processing.

- **Personalized customer experience:** AI allows for the analysis of customer data and the provision of personalized recommendations, increasing the likelihood of a purchase. For example, systems like Amazon use AI to recommend products.

- **Chatbots and virtual assistants:** AI can automate customer interactions through chatbots that answer frequently asked questions and provide product information, significantly improving the level of service.

- **Data analysis and processing:** AI algorithms can process large amounts of data faster and more efficiently than humans, allowing for the identification of trends and the rapid development of solutions for optimizing sales processes.

The use of blockchain technologies, big data, and artificial intelligence opens up new possibilities for businesses [9]. These technologies not only improve efficiency and profitability, but also enhance the customer experience and foster more trusting relationships with consumers [11]. Companies that can integrate these technologies into their processes will be able to gain a competitive advantage in a rapidly changing economy.

Blockchain technologies, big data, and artificial intelligence in sales processes presented in table 2.

TABLE II. BLOCKCHAIN TECHNOLOGIES, BIG DATA, AND ARTIFICIAL INTELLIGENCE IN SALES PROCESSES

Technology	Application	Description
The Blockchain	Supply chain management	It ensures transparency and traceability of all transactions in the supply chain.
	Simplification of processes	Smart contracts automate the execution of transaction conditions, which speeds up processes.
	Increasing trust	All transactions are immutable and verifiable, which increases customer trust.

Technology	Application	Description
Big Data	Customer behavior analysis	It studies consumer behavior to create personalized offers.
	Optimization of pricing policy	Determines optimal prices based on historical sales and demand data.
	Forecasting demand	It uses algorithms to predict future customer needs, improving inventory management.
Artificial intelligence	Personalizing the customer experience	It analyzes customer data and provides personalized recommendations.
	Chatbots and Virtual Assistants	It automates customer interactions and improves service through chatbots.
	Data analysis and processing	Quick processing of large amounts of data to identify trends and optimize operations.

This table will help you to better visualize and understand how each of the technologies can be applied in the sales process and what benefits they can bring [2].

Developing proactive marketing in the digital economy

1. Understanding proactive marketing

- What is proactive marketing: A strategy that focuses on anticipating customer needs and market trends rather than just reacting to them.
- The difference between traditional and proactive marketing: Comparing proactive approaches with reactive ones.

2. Analyzing the current market situation

- Researching digital trends: Evaluating current trends in the digital economy (e.g., the growth of e-commerce, changes in consumer preferences).
- Analyzing the target audience: Developing consumer profiles based on data about their behavior and preferences.

3. Defining the goals and strategies of proactive marketing:

- SMART goals: Setting specific, measurable, achievable, relevant, and time-bound goals.
- Key strategies:
- Personalization of offers based on analyzed customer data.
- Creation of innovative content that anticipates audience interests.
- Use of adaptive pricing based on market data and consumer trends.

4. Implementation of modern technologies:

- Use of big data: Collection and analysis of data to predict customer behavior and develop cutting-edge offers.
- Real-time analytics: Development of monitoring systems to quickly respond to market changes.
- Artificial Intelligence: Applying AI to optimize marketing campaigns and personalize offers.

5. Integration of multi-channel approaches:

- Creating an omnichannel strategy: Integrating all available channels (search, social media, email, mobile apps) to create a unified user experience.
- Synergy between online and offline channels: Connecting online promotions with physical stores and events.

6. Evaluating the effectiveness of proactive marketing:

- Metrics and KPIs: Defining key performance indicators to measure the success of marketing initiatives.
- Collecting customer feedback: Using surveys and feedback analysis to understand consumer perceptions.
- Continuous improvement based on feedback: Adapting strategies based on analysis results and market changes.

7. Examples of successful proactive marketing:

- Company cases: Examples of brands that have used proactive marketing to achieve success.
- Achieved results: Analysis of positive business results and changes in customer behavior.

IV. CONCLUSION

Digital transformation of sales processes:

- The implementation of information technologies in sales processes allows for the automation of routine tasks, improving the efficiency of customer interaction and improving data management. The use of CRM systems, e-commerce platforms and analytical tools helps to create a more personalized and accessible customer experience, which in turn contributes to increased sales volumes [13].

Proactive marketing:

- Applying a proactive marketing approach gives companies the opportunity to anticipate customer needs and adapt to changes in the market environment. The use of big data and real-time analytics helps to more accurately predict consumer behavior and create offers that meet their expectations. This proactive approach not only helps to attract new customers, but also increases the loyalty of existing ones.

Technology integration:

- The introduction of modern technologies, such as blockchain, artificial intelligence, and big data solutions, opens up new opportunities for optimizing procurement and sales processes. These technologies enable increased transparency, improved risk management, and more efficient collaboration with partners and suppliers.

Multichannel engagement:

- Adapting to consumer behavior requires an omnichannel strategy that provides a seamless

user experience across online and offline channels. This includes leveraging social media and marketplaces as sales channels and customer engagement platforms.

- Continuous learning and adaptation:

- The success of digital transformation and proactive marketing depends significantly on the company's ability to learn and adapt to new trends. Regular analysis of results, feedback from customers, and continuous process optimization are key factors for successful implementation of any strategies.

As a result, the integration of information technology and a proactive approach to marketing significantly increase business competitiveness, contribute to the creation of a unique customer experience, and ensure sustainable growth in the digital economy. Companies that can effectively implement these strategies will be ahead of their competitors and lead their industries.

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Student "Centaur" Competencies: Human-AI Synergy as the Foundation for Success in the Digital University of the Future

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Abstract— The article is dedicated to the study of emerging competency requirements for graduates in the context of the developing Digital University, which actively integrates artificial intelligence (AI) technologies. The concept of "centaur" competencies is proposed, implying not just the simple use of AI, but the development of synergistic interaction between humans and machines to solve complex problems. Key components of these competencies are analyzed: critical thinking in the context of AI, AI-enhanced creativity, adaptability, deep digital/AI literacy, and the ethics of AI interaction. Necessary changes in curricula and pedagogical approaches for the purposeful formation of "centaur" competencies are considered, including project-based learning and the development of skills for customizing AI solutions. The risks of cognitive atrophy due to excessive reliance on AI and strategies to counteract them are discussed. The role of the university in preparing students for the labor market of the sixth technological wave, where human-AI synergy will become the norm of professional activity, is substantiated.

Keywords— artificial intelligence, digital university, centaur competencies, human-AI synergy, future competencies, sixth technological wave, critical thinking, creativity, adaptability, digital literacy, AI ethics, labor market.

I. INTRODUCTION

The advent of the sixth technological wave and the widespread penetration of digital technologies, especially artificial intelligence, mark a profound transformation in all spheres of public life, including higher education (Decree of the President of the RF No. 490[1]; Shubaeva et al., 2023) [2]. The concept of the "Digital University" (Azarov, V. N. Strategy for the digitalization of the education system) [3] is ceasing to be a futuristic forecast and is becoming a reality, where AI is integrated into educational processes, administrative management, and scientific research (Buryy, Tsaplina, 2024[4]; Toktarova et al., 2023) [5]. Research shows both the immense potential of AI for personalizing learning, increasing its effectiveness and accessibility (Gurbannyyazov, Kuljayev, 2024[6]; Yakovets, 2023[7]; Korneeva, 2024) [8], and the associated challenges and risks (Osipova, 2024[9]; Lukichev, 2024) [10].

Under these conditions, traditional approaches to developing graduate competencies are proving insufficient. Simply knowing how to use AI as a tool is no longer enough. There is a need for a new type of specialist (Aniskina, N. N. Project management of digital transformation of organizations) [11], capable not just of applying AI, but of entering into productive synergistic interaction with it to solve non-trivial tasks. By analogy with "centaurs" in chess (human-computer pairs that outperform both grandmasters

and the most powerful supercomputers individually), we propose the concept of "centaur" competencies – a set of skills that allow humans and AI to collaborate effectively, achieving results unattainable by either alone. The purpose of this article is to reveal the content of "centaur" competencies and identify ways to form them within the digital university of the future.

II. THE CONCEPT OF "CENTAUR" COMPETENCIES: FROM TOOL TO PARTNER

The "centaur" idea involves a shift from perceiving AI as a simple tool (like a calculator or search engine) to understanding it as a cognitive partner. This means not delegating all intellectual work to AI, but building effective collaboration based on the mutual complementarity of strengths.

- Human Strengths: Critical thinking, goal setting, ethical assessment, intuition, empathy, contextual understanding, strategic vision, interpersonal interaction, higher-order creativity (generating fundamentally new ideas).
- AI Strengths: Processing vast amounts of data, identifying hidden patterns, computational speed, generating options, automating routine operations, predictive analytics (Toktarova et al., 2023[5]; Buryy, Tsaplina, 2024) [4].

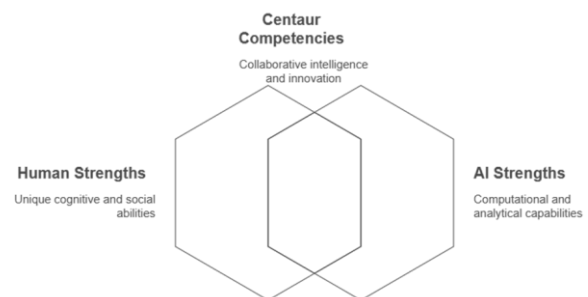


Fig. 1. "Centaur" Competencies

Synergy arises at the intersection of these capabilities. "Centaur" competencies are the human ability to effectively manage this interaction, directing AI's power to solve complex problems, critically evaluating its results, and integrating them into an overall strategy. The success of such interaction can be conceptually represented by the formula:

$$\text{CentaurEffectiveness} = f(\text{HumanCompetencies}, \text{AICapabilities}, \text{SynergySkills})$$

Where SynergySkills are precisely these "centaur" competencies, allowing for a result that exceeds the sum of

individual contributions: Result (Human + AI) > Result (Human) + Result (AI).

III. KEY "CENTAUR" COMPETENCIES FOR THE FUTURE STUDENT

Developing the ability for synergy with AI requires the cultivation of a specific set of competencies:

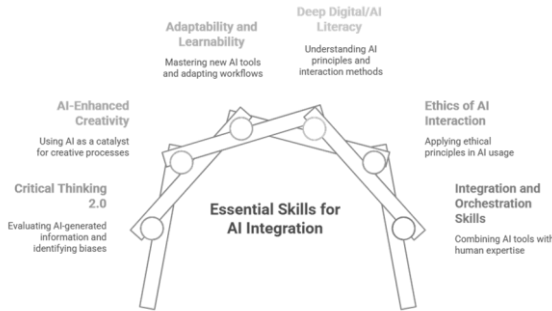


Fig. 2. Key "Centaur" Competencies for the Student

1. **Critical Thinking 2.0** (in the context of AI): This is not just information analysis, but the ability to deeply evaluate information generated by AI. This includes the skill to identify LLM "hallucinations," recognize bias in data and algorithms (Osipova, 2024) [9], assess the reliability of sources on which AI was trained, verify facts, and understand the limits of applicability of a specific AI model (Lukichev, 2024) [10].

2. **AI-Enhanced Creativity**: The ability to use AI not as a replacement for the creative process, but as its catalyst and co-author. This includes the skill to pose non-standard tasks to AI, use it for idea generation, prototyping, visualization, overcoming creative blocks, and finding unconventional solutions (e.g., in design, science, art).

3. **Adaptability and Learnability** (Meta-learning): AI technologies are developing exponentially. The ability to quickly master new AI tools, understand their logic, adapt one's workflows, and continuously relearn becomes key. This requires developed metacognitive skills – the ability to learn alongside AI.

4. **Deep Digital/AI Literacy**: Going beyond basic user skills. A conceptual understanding of the operating principles of major AI types (machine learning, neural networks, LLMs), their architecture (at least at an abstract level), data requirements, limitations, and capabilities is necessary. This also includes advanced proficiency in AI interaction methods, such as prompt engineering.

5. **Ethics of AI Interaction**: Understanding and applying ethical principles when working with AI. This includes issues of copyright for content created with AI participation, responsibility for decisions made based on AI recommendations, ensuring transparency in AI use, preventing discrimination embedded in algorithms, and protecting personal data (Osipova, 2024[9]; Toktarova et al., 2024) [5].

6. **Integration and Orchestration Skills**: The ability to effectively integrate AI tools into complex workflows, combining their capabilities with human experience, knowledge, and intuition. The skill to determine at which stage of a task it is advisable to apply AI, and where exclusively human intervention is necessary.

IV. RESTRUCTURING CURRICULA IN THE DIGITAL UNIVERSITY

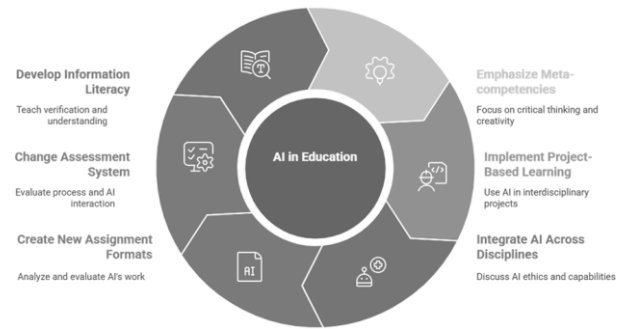


Fig. 3. Cycle of AI Integration in Education

- **Emphasis on Meta-competencies**: The priority should shift from transmitting factual knowledge (which is easily accessible via AI) to developing critical thinking, creativity, adaptability, problem-solving skills, and collaboration (including with AI).

- **Project-Based Learning (PBL)**: Implementation of complex interdisciplinary projects where students must use AI as part of a team to achieve a goal, while critically evaluating its contribution and making final decisions.

- **Integration of AI into all disciplines**: Issues of AI use, its capabilities, limitations, and ethics should be considered not only within IT specialties but also in the context of humanities, social sciences, natural sciences, arts, etc.

- **New Assignment Formats**: Assignments requiring not just finding information, but analyzing and evaluating AI's work, comparing different AI solutions, developing a strategy for AI use for a specific task, and creating something new in synergy with AI.

- **Changes in the Assessment System**: Not only final results but also the process of achieving them should be assessed, including the effectiveness of interaction with AI, justification for tool selection, critical evaluation of AI-generated data, and ethical application.

- **Development of Information and Media Literacy**: Special focus on teaching students to verify information, recognize deepfakes, and understand the mechanisms of algorithmic recommendation

V. TRAINING STUDENTS TO USE, CREATE, AND CUSTOMIZE AI

Preparing "centaurs" implies multi-level training in AI interaction:

- **Expert User Level**: All students should learn to effectively use existing AI tools (LLMs, image generators, data analysis systems), understand their strengths and weaknesses, master advanced query techniques (prompt engineering), and critically evaluate results.

- **Creator/Customizer Level** (for specialized fields): Students in IT, engineering, analytical, and other relevant specialties should acquire skills not only in using but also in basic development, fine-tuning, or customization of AI models for specific tasks in their subject area. This may include working with low-code/no-code platforms, learning the basics of Python and machine learning libraries, and working with AI service APIs. Examples of AI use in various subject areas and for different tasks (adaptive learning, recommendation systems, chatbots, data analysis, assessment

automation) are described in works by (Yakovets, 2023 [7]; Korneeva, 2024 [8]; Gurbannyyazov, Kuljaye, 2024 [6]).

It is important to emphasize that "centaur" competencies are formed at the intersection of deep subject knowledge and AI literacy. AI does not replace the need for fundamental training but provides new tools for its application and development.

VI. THE PROBLEM OF COGNITIVE ATROPHY AND COUNTERACTION STRATEGIES

One of the serious risks associated with the widespread adoption of AI is the potential "atrophy" of students' cognitive skills (Lukichev, 2024) [10]. Excessive reliance on AI for solving academic tasks can lead to a decline in abilities for independent critical analysis, information retention, and problem-solving without technological support. This threatens the quality of education and graduates' ability to think independently.

Strategies to counteract cognitive atrophy:

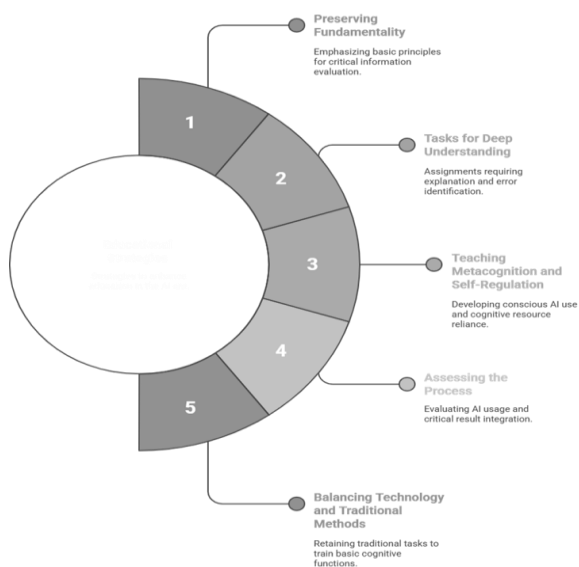


Fig. 4. Strategies to Counteract Cognitive Atrophy

- **Preserving Fundamentality:** Strengthening the emphasis on studying basic principles and concepts in subject areas that form the basis for understanding and critically evaluating any information, including that generated by AI.

- **Tasks for "Deep Understanding":** Introducing assignments that require not just finding or generating an answer with AI, but explaining the underlying principles, identifying logical errors in AI's reasoning, comparing AI and human approaches, and integrating AI results into a broader context.

- **Teaching Metacognition and Self-Regulation:** Developing students' skills for conscious AI use – understanding when its application is appropriate and effective, and when it is necessary to rely on one's own cognitive resources.

- **Assessing the Process, Not Just the Result:** Focusing on evaluating how the student used AI, how critically they approached its results, and how they integrated them into their work.

- **Balancing Technology and Traditional Methods:** Retaining tasks in the educational process that require work without AI (e.g., writing essays by hand, solving problems

without a calculator/AI assistant, oral exams) to train basic cognitive functions.

VII. PREPARING FOR LABOR MARKET 6.0: THE DEMAND FOR "CENTAURS"

The sixth technological wave is shaping a new labor market where the key success factor is the ability to effectively interact with intelligent systems. Professions are not so much disappearing as transforming, requiring specialists to have new, "centaur" competencies (Kalitvin, Frolova, 2020) [11]. Employers will need graduates who:

- Can set tasks for AI and interpret its results.
- Are capable of critically evaluating AI solutions and taking responsibility for them.
- Can use AI to enhance their own productivity and creativity.
- Possess flexibility and adaptability to work with constantly evolving technologies.
- Have strong communication and collaboration skills for working in mixed human-machine teams.

The task of the digital university is not just to give students current knowledge and skills in using AI, but to purposefully form "centaur" competencies, ensuring the competitiveness of graduates in the future labor market. This requires a proactive stance, revision of educational standards and programs, and investment in teacher training.

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Application of Artificial Intelligence in Education. From Consumer to Co-creator: What to Teach Students of the Digital University in the Era of Developing AI

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Abstract—The article explores the evolution of educational needs and necessary competencies for students amidst the rapid development of artificial intelligence (AI) and the emergence of the Digital University. It analyzes the transition from the paradigm of teaching the use of AI as a tool to developing students' ability to act as co-creators, critical evaluators, and ethical navigators in a world saturated with intelligent systems. Key didactic tasks are considered: developing deep AI literacy, including understanding the fundamental principles, classifications, parameters, and limitations of AI; forming "centaur" competencies for synergistic interaction with AI; teaching the basics of prompt engineering and customization of AI solutions; instilling skills of ethical reflection, understanding legal aspects, and responsible application of AI; as well as preparing for lifelong learning in the context of constantly evolving AI technologies. Futuristic aspects of further AI integration into education and life, and the corresponding challenges for educational programs, including the need to develop promising research directions, are discussed.

Keywords—artificial intelligence, digital university, future competencies, AI literacy, "centaur" competencies, prompt engineering, AI ethics, legal aspects of AI, lifelong learning, futurology of education, AI pedagogy, machine learning, natural language processing, computer vision

I. INTRODUCTION

The Sixth Technological Paradigm not only transforms existing industries – it creates a new reality where artificial intelligence (AI) becomes not just a technology, but a fundamental component of human activity and cognition (Decree of the President of the RF No. 490) [1], (Azarov et al., "Digital university: transformation...", 2024) [2]. AI is defined as a field of computer science concerned with creating systems capable of performing tasks that require

intelligence analogous to human intelligence, including learning, reasoning, perception, language understanding, decision-making, and problem-solving. The Digital University, as the vanguard of this transformation, faces an unprecedented task: to prepare students not for today, but for a future whose contours are largely determined by the exponential development of AI. Traditional approaches focused on transferring knowledge and forming skills for using existing tools are rapidly becoming obsolete (Quality management of digital products and digital transformation projects/ A.V.Chekmareva A.V., Azarov V.N [3].

Research shows that AI is already actively penetrating the educational process, offering tools for personalization, automation, and efficiency enhancement (Buryi, Tsaplina, 2024 [4]; Toktarova et al. "Empirical study...", 2024; [5] Yakovets, 2023 [6]). However, as many authors note, successful AI integration requires not only technological equipment but also a radical rethinking of what and how we teach students (Osipova, 2024; [7] Lukichev, 2024; [8] Romanova, 2023 [9]). The purpose of this article is to identify key areas of student learning in the Digital University that will enable them not just to consume AI capabilities, but to become its active, critically thinking, and ethically responsible co-creators and navigators in the complex world of the future.

II. BEYOND BASIC AI LITERACY: FUNDAMENTAL PRINCIPLES, CLASSIFICATION, AND CRITICAL UNDERSTANDING

Simply knowing how to use off-the-shelf AI services will not be enough in the near future. The Digital University must instill in students a deep, conceptual understanding of AI (Figure 1).

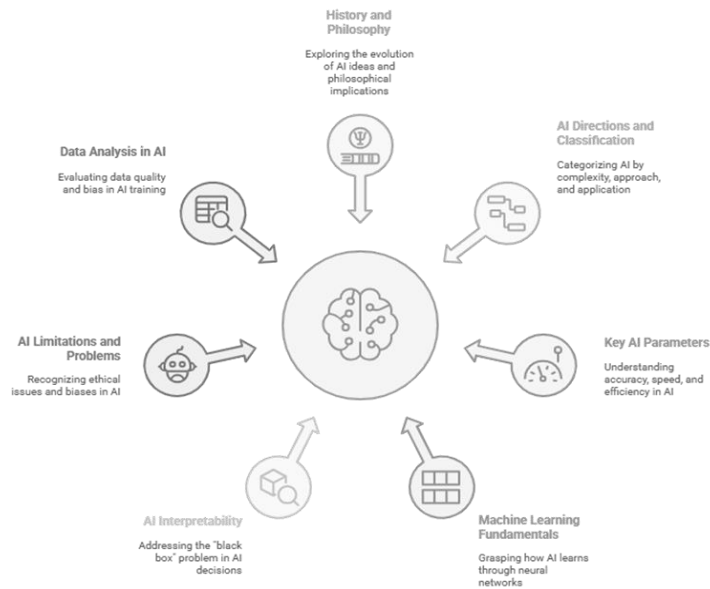


Fig. 1. Conceptual understanding of AI

What to teach:

- * History and philosophy of AI: Understanding the evolution of ideas, key concepts, and associated philosophical problems.

- * Main directions and classification of AI: Studying areas such as machine learning (ML), natural language processing (NLP), computer vision, and expert systems. Understanding AI classification by complexity level (narrow, general, super-AI), approach and method (rules and logic, ML, deep learning), application (NLP, computer vision, robotics), and degree of autonomy (autonomous systems, partially controlled systems).

- * Key AI parameters: Familiarity with parameters such as accuracy, speed, learnability, interpretability, and efficiency.

- * Fundamentals of machine learning (ML) and neural networks: Conceptual understanding of how AI "learns," what neural networks and LLMs are, their architectural features, and principles of operation (Toktarova et al., "Artificial intelligence technologies...", 2023) [10].

- * The "black box" problem and AI interpretability: Awareness of the difficulty in explaining the decisions of

many AI systems and familiarity with methods for increasing interpretability (XAI).

- * Limitations, problems, and "failures" of AI: Studying known limitations, including ethical issues, security and confidentiality, impact on jobs, algorithmic bias, technological dependence, uncertainty, and system complexity. Students must understand that AI is not a magic wand (Osipova, 2024; [7] Lukichev, 2024; [8]).

- * Data analysis and its role in AI training: Understanding the impact of the quality, representativeness, and bias of training data on AI performance. Teaching the basics of critical dataset evaluation and data augmentation methods.

III. FOSTERING SYNERGISTIC INTERACTION

A key task is to develop students' ability for synergistic interaction with AI (Figure 2). Students should possess a wide range of competencies, including digital literacy, critical thinking, analytical skills, basic programming knowledge (Python), information retrieval skills, communication skills, ethical understanding, flexibility, adaptability, and project management skills.

What to teach (in addition to the competencies mentioned above):

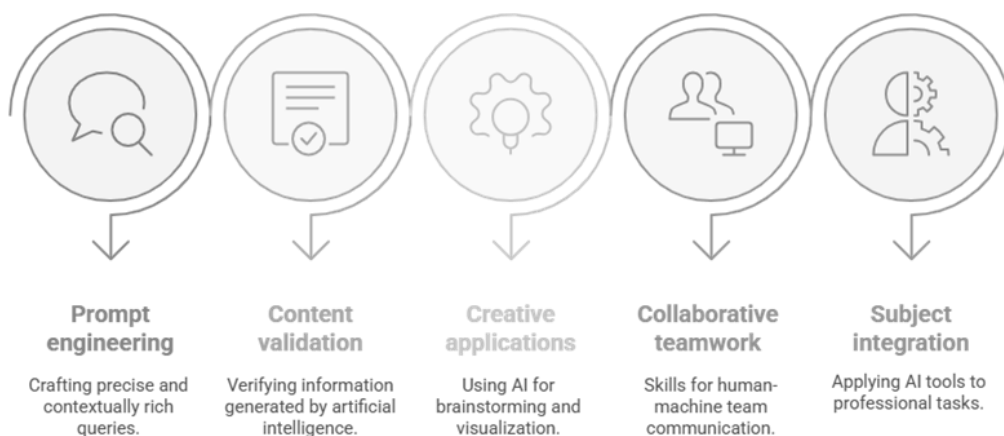


Fig. 2. Synergistic interaction with AI

* Advanced prompt engineering: The art of formulating precise, contextually rich, and multi-step queries.

* Critical validation and fact-checking of AI-generated content: Developing skills for quick and effective verification of information generated by AI.

* AI as a tool for expanding creativity: Teaching the use of AI for brainstorming, idea generation, prototyping, and visualization (Novoselov, Kukin, 2024) [11].

* Skills for collaborative work in human-machine teams: Understanding role distribution and effective communication.

* Integration of AI into subject-specific tasks: Teaching the application of AI tools to solve specific professional tasks (Gochamanov, 2024; [12] Korneeva, 2024) [13]. Main areas of AI application in education include adaptive learning,

student data analysis, automated assessment, interactive assistants, content creation, and teacher support.

IV. TEACHING THE BASICS OF CUSTOMIZATION, ADAPTATION OF AI SOLUTIONS, AND PROGRAMMING

As AI technologies develop, the ability not only to use ready-made solutions but also to adapt them or participate in their creation becomes increasingly important. The curriculum should include programming fundamentals (Python, working with NumPy, Pandas, Jupyter libraries), statistics and mathematics for AI (basics of statistics, linear algebra, introduction to probability), machine learning fundamentals (types, algorithms, practical exercises), data handling (collection, cleaning, visualization, SQL), deep learning (neural networks, TensorFlow/PyTorch), AI applications in various fields, and project work.

- What to teach (depending on the specialization):

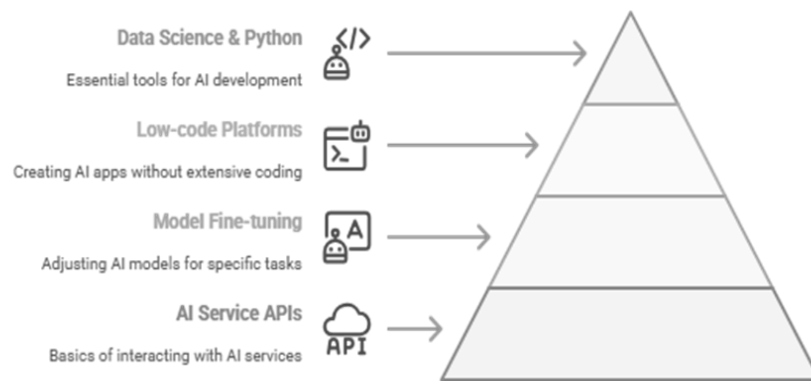


Fig. 3. Basics of customization, adaptation of AI solutions, and programming

* Basics of working with AI service APIs.

* Fine-tuning models.

* Low-code/No-code platforms for creating AI applications.

* In-depth study of Data Science and Python.

V. ETHICAL REFLECTION, LEGAL ASPECTS, AND RESPONSIBLE APPLICATION OF AI

Ethical and legal aspects of AI application are coming to the forefront. The Digital University must cultivate in students the ability for independent ethical reflection and responsible behavior.

What to teach:

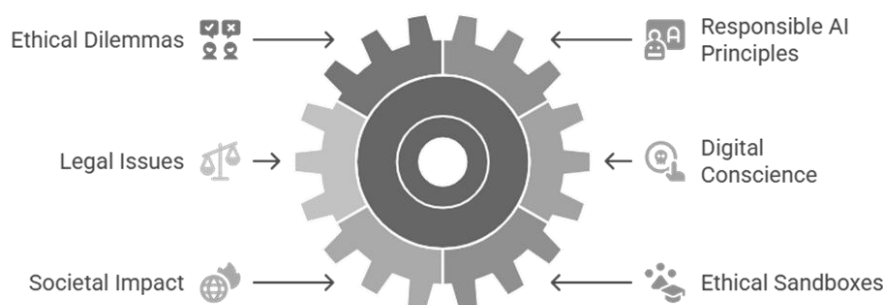


Fig. 4. Ethical and legal aspects of AI

* Analysis of ethical dilemmas related to AI: Bias, discrimination, job loss, copyrights, fakes, deepfakes.

* Principles of responsible AI development and use: Transparency, accountability, fairness, safety, privacy. Training should consider rules and methodologies for AI application, including ethical norms, data handling, model training and testing, and modularity.

* Legal issues: Data protection and confidentiality (GDPR), copyright and intellectual property for AI-generated content, quality and responsibility for AI errors, ethics and discrimination, licensing and accreditation of AI-integrated educational programs. Businesses and educational institutions must be attentive to these aspects.

* The individual's "digital conscience": Fostering personal responsibility for AI use.

- * Impact of AI on society and human rights.
- * Learning through ethical "sandboxes."

VI. PREPARING FOR LIFELONG LEARNING IN THE AI ERA (LIFELONG LEARNING WITH AI)

AI technologies are evolving rapidly. A key task is to instill in students the mindset and competencies for continuous learning alongside AI.

- What to teach:

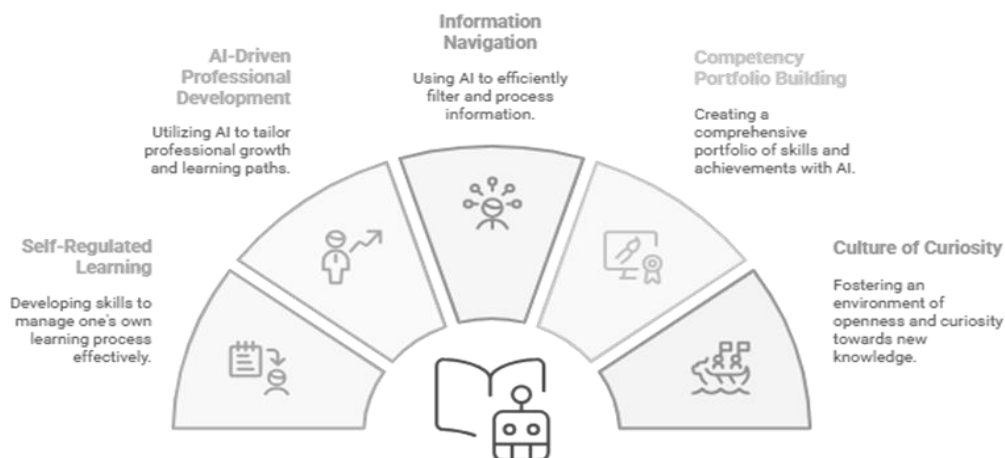


Fig. 5. Preparing for lifelong learning in the AI era

- * Self-Regulated Learning skills.
- * Using AI for personalized professional development.
- * Navigating the flow of information with AI assistance.
- * Building a "competency portfolio" using AI.
- * A culture of curiosity and openness to new things.

Futuristic Aspects, Promising Research, and Challenges for Educational Programs

Looking ahead, further deepening of AI integration can be anticipated, which will require new promising research in education. Directions include developing adaptive platforms, analyzing big data for success prediction, creating virtual tutors, real-time feedback systems, automating assessment, modeling and simulations, supporting teachers, developing interactive content, inclusive education, and improving access to education through global platforms.

- AI as a personalized cognitive exoskeleton. What to teach? Skills for effective "merging" while maintaining autonomy.
- Generation of fully adaptive and immersive AI educational environments. What to teach? Navigation and interaction in such environments, basics of their design.
- "Living" textbooks and knowledge, constantly updated by AI. What to teach? Working with "fluid" information, building a cognitive map.
- The problem of "digital immortality" and educational heritage. What to teach? Basics of "digital archaeology" and the ethics of knowledge preservation.

VII. CONCLUSION

Educating students in the Digital University of the AI era is a challenge that requires a fundamental rethinking of the goals, content, and methods of education. The transition from preparing consumers of AI technologies to forming co-creators capable of deep synergy with intelligent systems is becoming a key imperative. This means an emphasis on

developing a fundamental understanding of AI, its classifications, parameters, problems, and prospects; critical thinking in the context of its application; creativity enhanced by AI; ethical and legal responsibility; and, crucially, the ability for lifelong learning in a world where AI is constantly evolving.

Despite potential risks (unequal access, data quality, confidentiality, over-reliance, bias, difficulty of adaptation, job concerns, limited human interaction), the correct and ethical use of AI can significantly improve the quality of education. The Digital University must become a laboratory of the future, where students learn to live, work, and create in harmony with artificial intelligence, preserving and enhancing their human uniqueness and potential.

An example of an educational program that allows for a detailed exploration and conveyance of all the aforementioned aspects to the student (listener) is attached to the article; this program is an example and can be supplemented with sections and topics as needed.

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Cognitive Offloading or Atrophy? Risks of Skill Degradation and New Forms of Dependence in the Era of Pervasive Artificial Intelligence

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Abstract— This article analyzes the critical risks associated with the widespread adoption of artificial intelligence (AI) technologies in daily life and professional activities, particularly the phenomenon of "cognitive offloading" and its potential transition into the atrophy of fundamental cognitive skills. The mechanisms for the formation of new forms of technological dependence on AI systems are examined. Based on an analysis of existing research and empirical data (where possible), the impact of AI on cognitive functions such as memory, attention, critical thinking, navigation, and decision-making skills is assessed. Potential long-term negative consequences for individual and collective intelligence are discussed, as well as challenges for educational systems and human capital development strategies in the context of the sixth technological paradigm.

Keywords— artificial intelligence, cognitive offloading, skill atrophy, technological dependence, cognitive functions, critical thinking, memory, attention, neuroplasticity, education, sixth technological paradigm.

I. INTRODUCTION

The exponential development and pervasive integration of artificial intelligence (AI) technologies into the fabric of modern civilization herald not only an era of unprecedented opportunities but also a source of profound, often underestimated risks to the human cognitive apparatus. The delegation of an increasing number of intellectual tasks to AI systems, from routine calculations to complex analytical operations and creative generation, leads to a phenomenon that can be termed "cognitive offloading." However, if this process is not accompanied by conscious compensatory mechanisms and a rethinking of educational paradigms, it inevitably risks transforming into the atrophy of fundamental cognitive skills and the formation of new, more sophisticated forms of technological dependence. This article aims to critically analyze these risks, drawing on existing scientific data and frankly assessing the potential negative consequences for the future of human intelligence.

II. THE PHENOMENON OF "COGNITIVE OFFLOADING": THE FLIP SIDE OF CONVENIENCE

"Cognitive offloading" is the process of transferring cognitive tasks to external resources, be it a notebook, a calculator, or, in the modern context, complex AI algorithms. This strategy itself is not new and is often an adaptive mechanism that allows for the conservation of mental effort for more priority tasks. AI systems, such as search algorithms, navigators, automatic translation systems, organizers, and generative models, greatly enhance the possibilities for such offloading. We "offload" tasks of memorizing facts, orienting in space, performing

calculations, writing texts, and even making routine decisions onto them.

An undeniable advantage is the increase in efficiency and productivity in certain types of activities. However, it is critically important to ask: what happens to the "offloaded" cognitive functions in the long term? The answer, supported by research in related fields, is that unused or insufficiently stimulated neural pathways and cognitive skills tend to weaken and degrade.

III. FROM OFFLOADING TO ATROPHY: NEUROPLASTICITY AND THE RISK OF SKILL LOSS

The human brain possesses a high degree of neuroplasticity – the ability to change under the influence of experience. The "use it or lose it" principle is fundamental to understanding brain function. When certain cognitive functions are systematically delegated to external systems, the corresponding neural networks receive less stimulation, which can lead to their weakening.

Let us consider specific examples and potential risks:

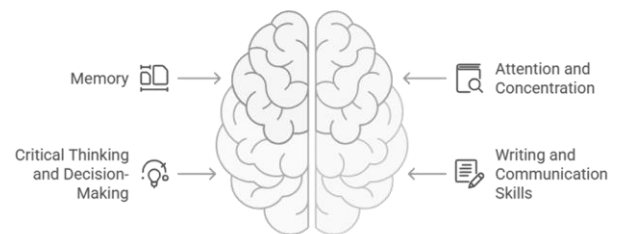


Fig. 1. Impact on skills and abilities

- Memory:
 - o "Google Effect" (or digital amnesia): Research shows that people remember information less well if they know it can be easily found on the internet. Sparrow, Liu, and Wegner (2011) in their landmark study demonstrated that participants were better at remembering where information was stored rather than the information itself if they were told that access to it would be preserved [1]. While this can be seen as an adaptive strategy, constantly "offloading" factual memory to AI risks weakening the ability to form and retain one's own structured knowledge bases, necessary for deep understanding and creativity.
 - o Spatial memory and navigation: Excessive reliance on GPS navigators may lead to reduced activity in the hippocampus – a brain region

critical for spatial memory and navigation. A study of London taxi drivers by Maguire et al. (2000) showed a significant increase in the volume of the posterior hippocampus in drivers forced to memorize a complex city map, compared to a control group [2]. Although direct research on the long-term impact of GPS on brain structure is still insufficient, it is logical to assume that the systematic "disengagement" of one's own navigational abilities does not occur without consequences. Recent studies are beginning to confirm these concerns, indicating that GPS use is associated with poorer spatial memory during subsequent navigation without it [3].

- **Attention and Concentration:**

Constant access to AI assistants and multitasking in the digital environment contribute to the formation of "scattered" attention and a reduced capacity for deep, sustained concentration, which is necessary for solving complex problems and creative processes. AI systems, optimized for providing quick answers, can exacerbate this trend, discouraging independent, thoughtful search and analysis.

- **Critical Thinking and Decision-Making:**

When AI offers ready-made solutions or recommendations (e.g., in choosing products, investment strategies, medical diagnoses), the need for independent information gathering, critical analysis, weighing alternatives, and taking responsibility for decisions is reduced. This is particularly dangerous in situations where AI

algorithms may be biased or erroneous (Osipova, 2024) []. Excessive trust in the "black box" of AI without understanding its operating principles and limitations is a direct path to the degradation of critical thinking skills.

Generative AI, capable of creating plausible but not always accurate or ethically sound texts, threatens the ability to distinguish facts from fiction and to form one's own reasoned opinion (Lukichev, 2024). []

- **Writing and Communication Skills:**

Automatic proofreading and text generation by AI can lead to a weakening of spelling, grammar, and stylistic skills. If AI constantly "completes thoughts" and "corrects," the incentive for independent improvement of these skills diminishes.

The impact on interpersonal communication also requires study, as interaction predominantly with AI agents may impoverish the experience of live communication and understanding non-verbal cues.

IV. NEW FORMS OF AI DEPENDENCE: A VICIOUS CYCLE

In addition to the atrophy of specific skills, pervasive AI creates prerequisites for the formation of new, deeper forms of technological dependence. If previous generations of technological dependencies (e.g., on television or the internet) were mainly related to content consumption or social validation, then dependence on AI can affect fundamental cognitive processes and decision-making mechanisms.



Fig. 2. Forms of dependence

- **Dependence on "cognitive crutches":** When AI becomes an indispensable "crutch" for memory, navigation, analysis, or writing, loss of access to it (e.g., due to a technical failure, lack of internet, or developer restrictions) can lead to a state of helplessness and inability to perform previously manageable tasks.

- **Emotional dependence on AI companions:** The development of empathetic chatbots and virtual assistants carries the risk of forming emotional attachments, especially among vulnerable populations. This can lead to the substitution of real human connections and exacerbation of social isolation.

- **Dependence on AI recommendations and "filter bubbles":** AI algorithms that shape news feeds, recommend content and products, create "filter bubbles," limiting access to alternative viewpoints and impoverishing one's worldview.

This reduces the ability for independent search and critical evaluation of information, fostering dependence on the algorithm-proposed vision of reality.

- **"Learned helplessness" in the face of AI:** If AI constantly offers "optimal" solutions and takes responsibility for complex tasks, individuals may develop a belief in their own incompetence and inability to cope without AI, which suppresses initiative and the drive for development.

V. 4. CHALLENGES FOR EDUCATION AND HUMAN CAPITAL DEVELOPMENT STRATEGIES

The identified risks pose direct and urgent challenges to the educational system and human capital development strategies:

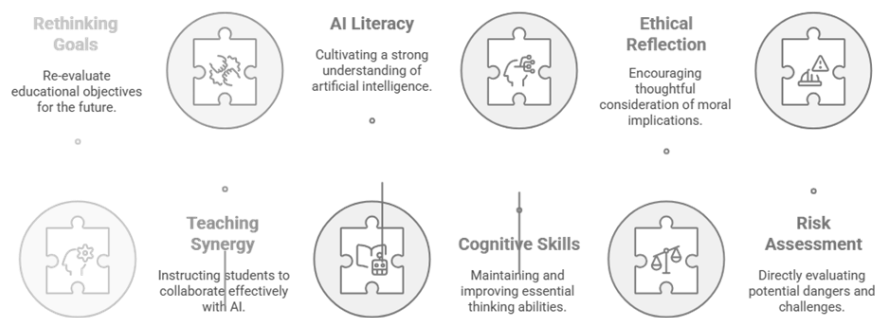


Fig. 3. Challenges for education

- **Rethinking the goals of education:** The focus must shift from the mere transmission of knowledge (which is easily "offloaded" to AI) to the development of metacognitive skills, critical thinking, creativity, adaptability, and the capacity for lifelong learning in the face of constant technological changes.

- **Teaching "synergy with AI," not blind subordination:** It is necessary to cultivate competencies that allow individuals to use AI as a powerful tool while retaining the functions of goal-setting, critical evaluation, and final decision-making.

- **Developing a high level of "AI literacy":** Students should not only know how to use AI but also understand its fundamental operating principles, classifications, key parameters, limitations, and the ethical and social consequences of its application.

- **Preserving and developing fundamental cognitive skills:** Educational programs must include tasks and methods that purposefully train memory, attention, writing skills, mental arithmetic, and logical thinking without reliance on AI, to prevent their atrophy. This may require revising curricula and rejecting the excessive technologization of certain aspects of learning.

- **Fostering ethical reflection:** Teaching students to analyze ethical dilemmas related to AI, as well as legal aspects, and fostering personal responsibility for its use.

- **Direct assessment of risks:** It is necessary to openly discuss with students not only the benefits but also the risks of cognitive offloading and dependence on AI, fostering in them a conscious attitude towards the use of technology.

VI. CONCLUSION: THE NEED FOR A CONSCIOUS APPROACH

Artificial intelligence is undoubtedly a technology with enormous transformative potential. However, the blind and

uncritical implementation of AI in all spheres of life, accompanied by uncontrolled "cognitive offloading," carries a direct threat of degrading fundamental human skills and forming new, more dangerous forms of dependence. The atrophy of memory, attention, and critical thinking is not a hypothetical scare tactic but a very real risk, confirmed by the principles of neuroplasticity and initial empirical data.

A frank assessment of these risks and the development of proactive strategies at the level of educational systems, public policy, and individual choice is an absolute necessity. The task is not to abandon the benefits of AI, but to learn to use it consciously, preserving and developing our own cognitive potential, and to prevent the convenience of "cognitive offloading" from turning into irreversible atrophy of human intelligence. The future belongs not to those who completely delegate thinking to machines, but to those who can build a truly synergistic and critically considered partnership with them.

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Caspian Pipeline Consortium Equipment Monitoring System

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Abstract - The equipment condition assessment system of the Caspian Pipeline Consortium is purposed to enhance the efficiency of monitoring and to manage the operation of pipeline systems. The primary objective of this initiative is to develop an information system that enables continuous monitoring of pipeline conditions, thereby minimizing maintenance costs and reducing risks associated with potential failures. To achieve this goal, several tasks have been defined, including the analysis of existing pipeline condition assessment methods, the collection and structuring of data, the application of statistical analysis to identify patterns, and the development of a predictive model for equipment condition. The most important aspect is the evaluation of the effectiveness of the predictive model, which will justify its feasibility and advantages over traditional approaches.

Keywords – Condition assessment, Monitoring, Information systems, Predictive Analytics, Digital twin, Caspian Pipeline Consortium.

I. INTRODUCTION

In the context of rapid scientific and technological progress, ensuring the reliability and efficiency of pipeline systems has become one of the key challenges in the oil and gas industry. The Caspian Pipeline Consortium (CPC) is a significant international initiative focused on oil transportation, bringing together Russia, Kazakhstan, and major global oil companies such as Chevron, Shell, ExxonMobil, Eni, British Gas, Rosneft, and Lukoil. The consortium was formed to build and operate a 1,500-kilometer main oil pipeline, facilitating the efficient transport of oil across the region. In 2024, the Debottlenecking Program (DBNP) was successfully implemented, increasing the pipeline's throughput capacity and enabling the transportation of additional volumes of crude oil from Kazakh fields.

The Caspian Pipeline Consortium, with its significant resources and technological capabilities, faces a number of challenges related to maintaining the reliability of its main pipelines. Amid the global trend toward digitalization of industrial processes, the pressing task is the implementation of innovative monitoring and condition assessment systems that contribute to optimizing operational costs and enhancing overall safety levels. The objective of this work is to systematize approaches to pipeline condition assessment and to develop an Intelligent Equipment Condition Assessment System (IECAS), which will enable real-time monitoring, prediction of potential emergency situations, and prompt decision-making aimed at minimizing the consequences of failures.

Within the framework of the IECAS project, the primary focus will be on the collection, storage, and statistical processing of data on the pipeline's condition throughout its

entire lifecycle, including preparatory operations, active operation, and decommissioning stages. The effective use of statistical analysis tools and predictive modeling to analyze equipment loads, environmental interactions, and operational parameters will significantly enhance the reliability of pipeline systems and reduce capital expenditures. The article will analyze current pipeline condition monitoring practices, assess the advantages of the proposed system compared to traditional diagnostic and monitoring methods, and determine the parameters of the economic impact of its implementation.

Thus, the aim of this article is to develop a system aimed at improving operational reliability and reducing maintenance costs for pipeline transportation systems, which will ultimately enhance the competitiveness of the Caspian Pipeline Consortium in the global market.

II. LITERATURE REVIEW

The article examines current research on the use of predictive analytics and digital twins to assess the status of industrial equipment. The reviewed sources cover various aspects of the development, implementation, and application of these technologies, as well as their impact on the efficiency of production processes.

Digital twins (DTs) are virtual replicas of physical objects or systems designed to monitor their status in real time, predict their functional, and optimize their performance. The concept of digital twins is actively evolving in the industry, offering new approaches to equipment management and monitoring. The authors of the paper [1] give a summary of the body of research on digital twins in industry. They explore the concept's development, look at several definitions and classifications of digital twins, and talk about the technology and use cases related to their use. The article also discusses the different meanings of the phrase "digital twin" and provides a brief analysis and multiple definitions. The article [2] explores the concept of a digital twin for pipeline integrity management. The authors note that traditional inspection methods, such as non-destructive testing (ultrasound, radiography) and in-line diagnostics, have several limitations: high costs, long intervals between inspections, and limited coverage areas. The proposed method entails building a dynamic digital model of the pipeline system, enabling the study of historical data, the simulation of potential anomalous situations, and real-time equipment performance tracking. The key methodologies discussed in the article include:

- Data-Driven Modeling: the use of machine learning algorithms for failure prediction;
- Physics-Based Modeling: the application of mathematical models for corrosion, material fatigue, and pressure changes;

- GIS Integration: visualization of pipeline conditions linked to geographic coordinates.

The authors conclude that a digital twin can reduce operational costs, enhance monitoring accuracy, and minimize the risks of emergencies.

The study [3] is dedicated to a review of digital twin technologies in the context of the industrial sector. The authors identify three key components of a digital twin:

- Virtual Modeling: the creation of a digital replica of a physical object;
- Data Integration and Real-Time Connectivity: continuous data exchange between the physical object and its digital representation;
- Analytics and Decision-Making: the application of machine learning and predictive analysis methods;

The article emphasizes that efficient data gathering, management, and predictive model application are necessary for the successful implementation of digital twins. The authors note that whereas digital twins have many advantages, there are also significant drawbacks and restrictions:

- High costs: a significant investment in sensors, software, and computer infrastructure is required to develop a digital twin;
- Integration complexities: many companies rely on older SCADA systems, which are often incompatible with modern technologies;
- Issues with data quality: digital twins depend significantly on vast quantities of precise data, whereas real-world data is sometimes erratic or noisy;
- Cybersecurity risks: digital twins are vulnerable to possible cyberthreats due to their dependence on cloud services and internet connectivity;

In the study [4], the application of digital twins in automated process control systems is also analyzed. The authors identify the limitations of using digital twins in production, review global experience, and outline potential directions for further research. Predictive analytics purposed to forecast future events based on historical data and statistical algorithms. In the industrial sector, it is used to predict equipment conditions, enabling the prevention of potential failures and the optimization of maintenance processes.

The article [5] examines forecasting methods and predictive analytics applied to support business decision-making. The authors analyze machine learning methods, statistical models and hybrid approaches, emphasizing that the use of hybrid methods and automated forecasting systems enhances accuracy and reduces the influence of human factors. This is particularly important for predicting equipment failures and optimizing maintenance.

The work [6] analyzes the impact of predictive analytics on company operations. The author explores various types of analytics based on big data, including descriptive, diagnostic, prescriptive, and predictive analytics, and highlights that predictive analytics enables companies to efficiently organize equipment operations, reduce the risks of expensive repairs, and save resources.

The study [7] focuses on the implementation of predictive analytics technology in high-tech industrial enterprises. The author examines key components of the industry, including

the Industrial Internet of Things (IoT), artificial intelligence, and predictive analytics, and notes that the successful implementation of predictive analytics requires the integration of these components to enhance equipment efficiency.

In the work by Khasanov [8], the challenges faced by predictive technical diagnostics and analytics are also discussed. The author notes that despite the rapid advancements in this sector, obstacles still stand in the way of predictive analytics' wider acceptance. Among these are the difficulties in obtaining high-quality data and incorporating it into current systems.

III. PROBLEM STATEMENT

1. Development of reliable data storage and processing system:
 - Establish a scalable data repository capable of efficiently managing large volumes of information, with the ability to classify and structure data for subsequent analysis;
 - Ensure long-term data storage with rapid access and analytical capabilities.
2. Design a database for IECAS tailored to the specific requirements of the task:
 - Implement support for both dynamic and static data;
 - Enable the integration of technical and economic indicators, manage access permissions, and ensure data integrity.
3. Support for predictive models:
 - Provide the capability to develop models that account for various external factors and specific operational parameters.

IV. METHODS

To achieve the set, modern methods of data analysis, digital modeling, and design of information systems are employed. The research methodology encompasses three key areas aimed at enhancing pipeline reliability, optimizing maintenance costs through the use of information systems, reducing the likelihood of emergency incidents. The research methodology covers three key areas: increasing the reliability of pipelines, optimizing maintenance costs, reducing the likelihood of emergency situations.

A. Predictive Analysis

This method aims to forecast the condition of the pipeline and potential failures based on historical data and system performance metrics. Predictive analytics explores patterns and identifies underlying issues. To implement this method, the following data is required:

- Historical data on failures and repairs;
- Operational parameters;
- Technical and economic indicators.

Stages:

1. Classification: predicting the probability of equipment failure (the model determines the pipeline's condition: "normal," "requires attention," or "critical");
2. Regression: predicting time to failure;

3. Anomaly detection: identifying unusual deviations in data that may indicate an impending failure.

Tools used: Python, Jupyter Notebook.

B. Development of a Digital Twin

A digital twin of the pipeline system is a virtual model updated in real-time based on sensor data and predictive models. To implement this method, the following data is required:

- Topographic information;
- Pipeline design data;
- Current performance metrics;
- Historical failure data.

Stages:

1. Integration of data from multiple sources;
2. Use of Geographic Information Systems (GIS) for visualizing geospatial data;
3. Physical and mathematical modeling of the pipeline's condition.

Tools used: ArcGIS, QGIS – visualization of the digital twin; Python (Folium, Geopandas, Matplotlib) – working with maps and data.

C. Design of the Intelligent Equipment Condition Assessment System

Based on the conducted analysis of the processes of monitoring the condition of the CPC pipelines, requirements for the IECAS have been developed. The system should

allow for the accumulation of heterogeneous data on the condition of the CPC pipeline (sensing results, sensor readings, external monitoring data) in real time, their analysis using statistical and predictive models and visualization of the results in a geoinformation environment. IECAS requires a reliable and scalable database that provides storage, processing and analysis of information on the condition of pipeline infrastructure at all stages of the life cycle. The database is designed to integrate heterogeneous static and dynamic data and support predictive modeling.

In accordance with the technical requirements of the project a database structure was developed that included the following main entities: pipelines; pipeline_sections; sensors; sensors_data; diagnostics data; repairs; events (incidents and accidents); forecasts (failure probability forecasts); gis_visualization (data for GIS visualization); accident_losses; historical_repair_costs.

V. RESULTS

A. Generation and analysis of synthetic data

To test all subsystems of the intelligent equipment condition assessment system (IECAS), a synthetic dataset was formed that simulated the operational parameters of pipelines — pressure and temperature. The sample size was about 10,000 observations, which ensured the statistical stability of the analysis [10].

The pressure was modeled by a normal distribution with parameters: $\mu = 5.648$ bar, $\sigma = 1.349$ bar, temperature — $\mu = 24.91^\circ\text{C}$, $\sigma = 4.548^\circ\text{C}$.

The data are noisy to simulate field conditions. Figure 1 shows the histograms of the parameter distribution.

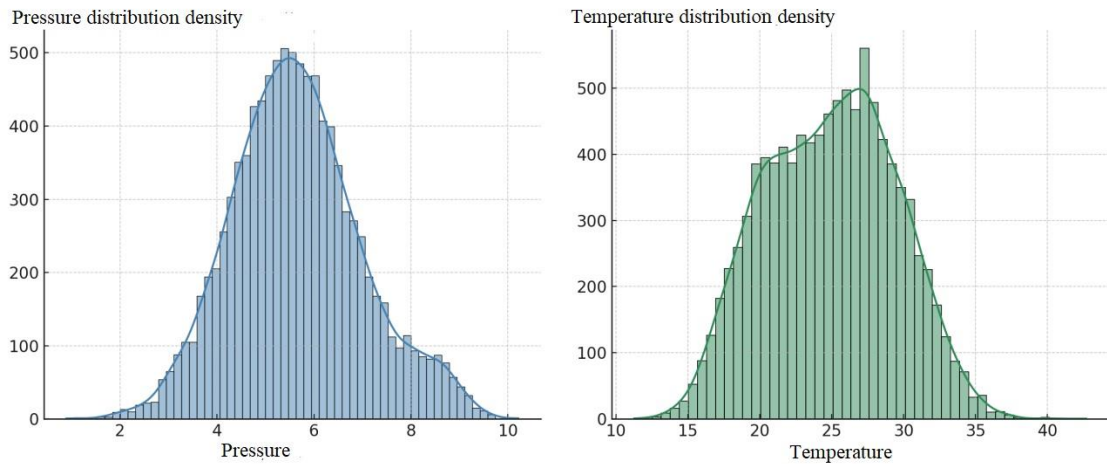


Fig. 1. Pressure and temperature distributions in the generated dataset.

The data is generated correctly, the ranges are realistic, the database architecture and processing algorithms have been successfully debugged.

B. Predictive model for failure prediction

The target variable was determined from the events table: areas were marked as failures if leak or accident events occurred within 30 days after observation.

Aggregated features were used for training: sensor_mean, sensor_max, sensor_std, sensor_count. Categorical features: criticality, soil_type, environment_typ.

To combat strong imbalance (failure rate < 0.2%), a synthetic increase in positive examples to 600 rows was used

with a total size of ~4500 records. The Random Forest algorithm was used with the class_weight='balanced' parameter and an 80/20 split.

The model quality metrics are given in Table 1:

TABLE. I. THE MODEL QUALITY METRICS

Model	Accuracy	Precision	Recall	F1-score	AUC-ROC
Random Forest	0.967	0.780	0.680	0.726	0.930
Decision Tree	0.918	0.740	0.660	0.694	0.910
Logistic Regression	0.903	0.720	0.480	0.573	0.905

As can be seen, the Random Forest model demonstrates the most balanced results across all metrics. It outperforms logistic regression across all metrics, and also shows better values than the decision tree in F1-score and AUC-ROC. This confirms its ability to maintain high prediction accuracy even in the presence of noise and a limited number of features.

C. Verification on an independent set

Based on the model predictions, an algorithm for calculating the risk index and automatically generating operational recommendations was implemented. The probabilistic assessment of failure is interpreted as follows:

- Probability > 0.7 — immediate diagnostics and repair are required;
- $0.3 \leq \text{probability} \leq 0.7$ — increased monitoring and additional examination;
- Probability < 0.3 — scheduled observation.

The model was tested on three sites differing in criticality, soil type and sensor values. The following predictions were obtained:

TABLE. II. RESULT OF VERIFICATION OF THE MODEL'S PERFORMANCE ON THE TEST DATA SET

Sensor_mean	Sensor_max	Sensor_std	Criticality	Sol_type	Environment_type	Probability of failure
5.6	9.3	2.1	high	1	3	0.786
3.1	6.7	1.2	medium	0	0	0.261
2.4	4.5	0.9	low	2	1	0.191

The model is robust, interpretable and enables automatic generation of site maintenance recommendations.

D. Visualization in QGIS

QGIS is tightly integrated with the MySQL DBMS: for this, connection parameters (host name, port, database, login, password) are specified in QGIS [11]. After the connection is established, the required tables/views become available as QGIS layers. Also, in QGIS DB Manager, you can execute SQL queries to the database. For example, the following query combines the route and sensor tables by the section_id field (road section identifier), extracting the geometry as WKT:

```
SELECT
    pr.section_id,
    ST_AsText(pr.geom) AS pipeline_geom,
    s.sensor_id,
    ST_AsText(s.geom) AS sensor_geom
FROM pipeline_route AS pr
LEFT JOIN sensors AS s
    ON pr.section_id = s.section_id;
```

In this example, the pipeline_route table contains the route geometry, and sensors contains the sensor data. The query selects a match by section_id, returning both geometries.

Integration with QGIS is implemented via connection to MySQL. Loaded:

- Pipeline geometry (polyline)
- Sensor positions (points)
- Soil zones (polygon, WKT)

Figure 2 demonstrates the layer structure:

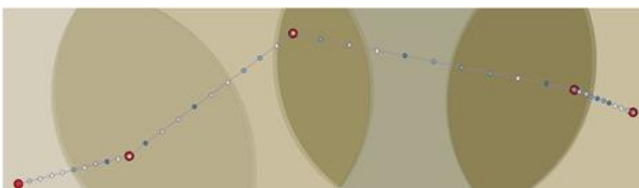


Fig. 2. Visualization of the linear pipeline route

The linear route connects the start and end points and passes through all the control points. The sensor points are placed along the route. The soil zones are shown as overlapping translucent ellipses/polygons of different shades. On the map, it may appear that the polygons of different soil zones overlap each other. The intersection of zones means that the land plot is characterized by several types of soil at the same time (mixed plot).

Geographical visualization is fully integrated, it is possible to build an interactive map displaying the equipment status in real time.

VI. CONCLUSION

As part of this work, a full-fledged intelligent system for assessing the condition of pipeline infrastructure equipment was implemented using the Caspian Pipeline Consortium as an example. The solution covers the entire cycle of information processing: from structuring and storing technical and economic data to predicting failures and visualizing risks on a geographic map.

The constructed architecture demonstrates how heterogeneous data sources can be combined into a single monitoring and analysis system. The use of machine learning allowed not only to automate the assessment of the probability of accidents, but also to generate clear operational recommendations. Integration with a geographic information system clearly demonstrated the prospects for the transition to spatially-oriented infrastructure management.

The results obtained can be used in industry to transition from reactive to predictive management of the technical condition of objects. The work also creates the basis for further expansion of the system - connecting additional data sources, scaling to other objects and creating a web interface based on GIS.

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Improving the Quality of Monitoring Facilities

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Abstract – The article substantiates the need to develop and apply automated monitoring systems for objects of various origins. Existing systems reviewed. It is noted that they do not allow real-time adjustment of the object parameters. Adjustment is possible, at best, in the next monitoring cycle, and more often after one or more cycles. Disclosed is a method of monitoring the state of an object based on a set of parameters, which improves the quality of monitoring objects. Distinctive features of proposed method are separation of monitoring cycle into several time intervals, measurement of monitored parameter value at the end of each monitoring interval and its comparison with model value calculated using mathematical model of object. Analysis of mismatch of actual parameter value with expected parameter value makes it possible to generate and implement control action depending on value of mismatch of actual parameter value with expected parameter value. Examples of the method for monitoring various objects are given.

Keywords – *automated remote monitoring systems, control object, controlled parameter, mismatch of parameter values.*

I. INTRODUCTION

In the modern world, filled with complex biological and technical objects, the problems of monitoring their condition come to the fore. For biological objects, this is due to the preservation of their quality characteristics that form health, for technical ones - to ensure their safe functioning.

Considering that there are a huge number of monitoring facilities and many of them are located in hard-to-reach or dangerous places for humans, as well as the fact that each of them needs to be monitored according to an individual set of parameters, automated remote monitoring systems come to the fore.

Automation of monitoring processes is the use of new technologies and tools to improve the solution of control tasks, which allows you to accelerate the result, improve its quality and reduce the cost of the monitoring process itself.

Automated remote monitoring of objects allows you to reduce the time it takes to complete tasks, reduce the likelihood of errors and increase the accuracy and quality of work [1].

In the process of transforming traditional monitoring systems into automated and remote ones, the number of functions they implement has significantly increased, they began to be used in an increasing number of subject areas. Today, monitoring systems are used almost everywhere: in

medicine, environmental protection, social work, production, etc.

Monitoring objects are complex systems. They are monitored using various types of sensors, as well as external monitoring devices. The data obtained about the objects are multidimensional time series of measurements of controlled parameters. Processing such data leads to significant time and other costs. Therefore, it is necessary to use computer systems capable of automatically generating monitoring programs [2].

Currently, formal models, methods and algorithms have been developed that make it possible to automate monitoring by automating data collection, as well as building models of monitoring objects based on incoming data [3, 4].

Automated remote monitoring of the state of human health and the environment is a type of telecommunication technology that allows you to track selected indicators of human health and the environment over time, accumulate this data in digital form, transmit it at a distance for specialists (doctors, ecologists) to assess the dynamics of human health and the environment in order to make a clinical or management decision [5].

Therefore, for successful automation of monitoring, it is necessary to use artificial intelligence, big data analysis and machine learning. These technologies can significantly improve the quality of monitoring [1].

The purpose of the work is to develop a method for remote monitoring of objects to improve the quality of monitoring.

To achieve the goal, it is necessary to solve the tasks of automation of monitoring and control of the state of the object in real time to correct its current state.

The results are supposed to be used to improve the quality of monitoring of objects of various origins, in order to improve public health, reduce the negative impact of industrial enterprises on the environment, and comprehensively assess the functioning of the enterprise.

II. MATERIALS AND METHODS

A. Human health monitoring facility

Experts call the code of a healthy heart a set of parameters and their values that correspond to the optimal norms for long-term preservation of the heart healthy. Optimal norms, peculiar codes, such correspondence is a set of the following parameters: blood pressure, heart rate,

physical activity, body mass index, stress resistance, attitude to smoking and alcohol, blood cholesterol.

Blood pressure is the pressure that blood exerts on the walls of blood vessels. As a rule, after an adequate reaction of the body to emotional or physical activity, at rest, blood pressure returns to normal after 15, maximum 30 minutes. For any adult, the optimal norm is blood pressure equal to 120/80 mm Hg. Art. Its repeated increase to 140/90 mm Hg. Art. And above - one of the signs of hypertension. The presence of hypertension on average by a third reduces the life expectancy of a person.

The heart rate in an adult should be rhythmic, without pauses and fall within the range of 60-80 bpm. Normally, the heart rate coincides with the pulse rate. If the physical and emotional load of the body is transferred normally, then after its completion, both the pulse and heart rate return to normal after a maximum of 30 minutes, as well as blood pressure.

Physical activity should be and correspond to the physical condition and level of training of the person involved. It should be regular. Only daily, regular physical movements create a training load on the cardiovascular system. Walking at an average pace of 30 - 40 minutes per day is considered the best physical activity. An adequate load is considered to be a replacement for walking by swimming, dancing, skiing or cycling. In this case, it is necessary to control blood pressure and heart rate before and after exercise.

Body mass index (I) - calculated by the formula:

$$I = \frac{m}{l^2}, \quad (1)$$

where m - body weight, kg; l - human height, m.

Table 1 shows the dependence of a person's weight on his height, expressed as body mass index

TABLE I CORRESPONDENCE BETWEEN HUMAN BODY WEIGHT AND HEIGHT BASED ON MASS INDEX [6]

Range of values of I, rel. units	The ratio between a person's weight and height
18,5 – 25	perfect
25 – 29	overweight
> 30	fatness

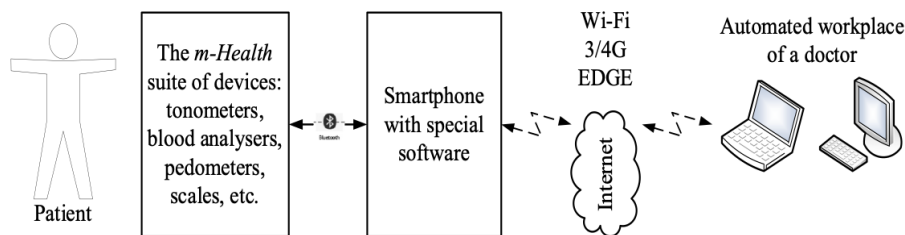


Fig. 1. Block diagram of an automated system for remote monitoring of human health

An automated system for remote monitoring of human health allows you to automate the processes of collecting data of human heart code parameters using specialized mobile devices (m-Health). Data is transmitted to the system via the Internet; the user immediately sees the value of the parameter and its assessment, including statistics of changes and recent history. If necessary, the user can provide access to this data to a doctor working in the same system for detailed analysis and receiving recommendations.

An automated system for remote monitoring of human health can be used to: collect data on the vital signs of the

People with obesity are advised to limit the total calorie content of food per day in the range of 1600-1800 kcal by reducing the consumption of fats and digestible carbohydrates and, of course, increasing physical activity.

Stress resistance - the ability to protect the body from the destructive influence of stress. Prolonged, excessive load quickly depletes the body's reserves, primarily the cardiovascular and nervous systems. The ability to be optimistic, to show flexibility in planning affairs taking into account rapidly changing conditions, the ability to neutralize negative emotions with various methods allows you to keep your heart healthy for many years. The most dangerous "stress neutralization methods" are smoking and alcohol intake.

Scientists have proven the harmful effects of tobacco smoke components on the walls of all vessels of the body. Moreover, both light cigarettes and secondhand smoke are harmful. Smokers have a multiplied risk of early and more severe cardiovascular diseases. The illusion of the positive effect of small doses of alcohol on the state of the heart is not confirmed by recent studies. It is absolutely unacceptable to take alcohol at any dose to people planning to have healthy children.

Blood cholesterol - determined by venous blood test. Cholesterol is not found in the food taken, but is produced only in the body. But excessive consumption of animal fats leads to the accumulation of cholesterol on the walls of the arteries and a complete blockage of their lumen. A healthy adult should aim for a blood total cholesterol reading below 5 mmol/L. The higher the risk of myocardial infarction or brain stroke, the lower the blood cholesterol should be.

To determine the values of these parameters, an automated system for remote monitoring of human health has been developed [7] (see Fig. 1).

human heart code, their transmission, storage and analysis by specialists; predicting and identifying risks of deteriorating human health; organization of prompt response in emergency situations; accompanying the recovery treatment process.

B. Environmental monitoring facility

One of the types of automated systems for remote monitoring of environmental objects is automatic systems for remote monitoring of emissions and discharges, developed in accordance with [8, 9].

The functional diagram of the predictive automatic measuring system for remote monitoring of emissions (discharges) is shown in Figure 2.

Such systems should provide measurement with a given error, computer processing and accounting of parameters:

- emissions: mass emission of a pollutant, g/s; pollutant mass concentration, mg/m³; exhaust gas temperature, °C; exhaust gas pressure, kPa; volume flow rate of exhaust gases, m³/s; oxygen content in exhaust gases, %; humidity of exhaust gases, %;
- discharges: pollutant concentration, mg/dm³; volume flow rate of discharged waste water, m³/h; temperature of discharged waste water, °C; hydrogen index of discharged waste water, pH units; chemical oxygen consumption,

mg/dm³; turbidity, units of turbidity by formazin.

Automatic systems for remote monitoring of emissions (discharges) are a single set of hardware and software that automatically measure and record the indicators of emissions (discharges) of pollutants, process, visualize, store and transfer reporting data on the indicators of emissions (discharges) of pollutants to the state register of facilities that have a negative impact on the environment.

These systems generally consist of the following subsystems and complexes: a predictive automatic measuring subsystem for monitoring emissions (discharges), a subsystem for collecting and processing data on emissions (discharges), a set of auxiliary equipment.

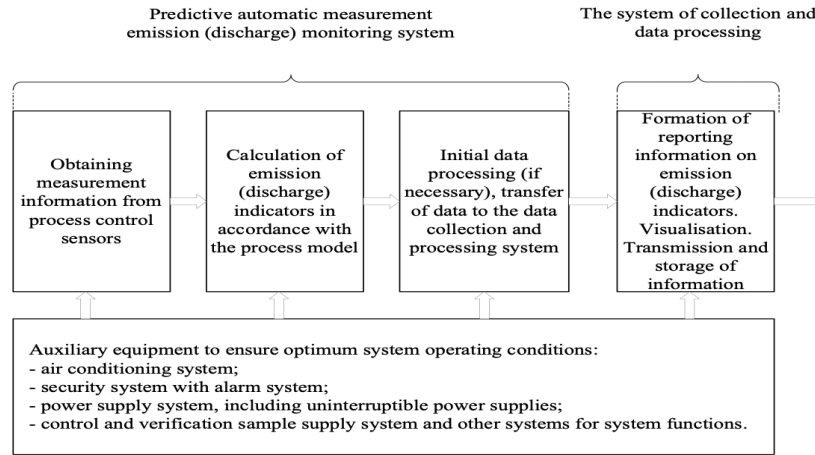


Fig. 2. Functional diagram of a predictive automatic measuring system for remote monitoring of emissions (discharges)

Depending on the technical design, some functions of the data collection and processing subsystem for data processing and accounting can be performed by the controller units of the measuring instruments. In the case of a predictive automatic measuring system for monitoring emissions (discharges), some functions of the data collection and processing subsystem for data processing and accounting can be performed by separate modules of the system software.

C. Method for automated control of object state

The authors have developed a method for automated control of the state of an object [10], the algorithm of which is shown in Figure 3.

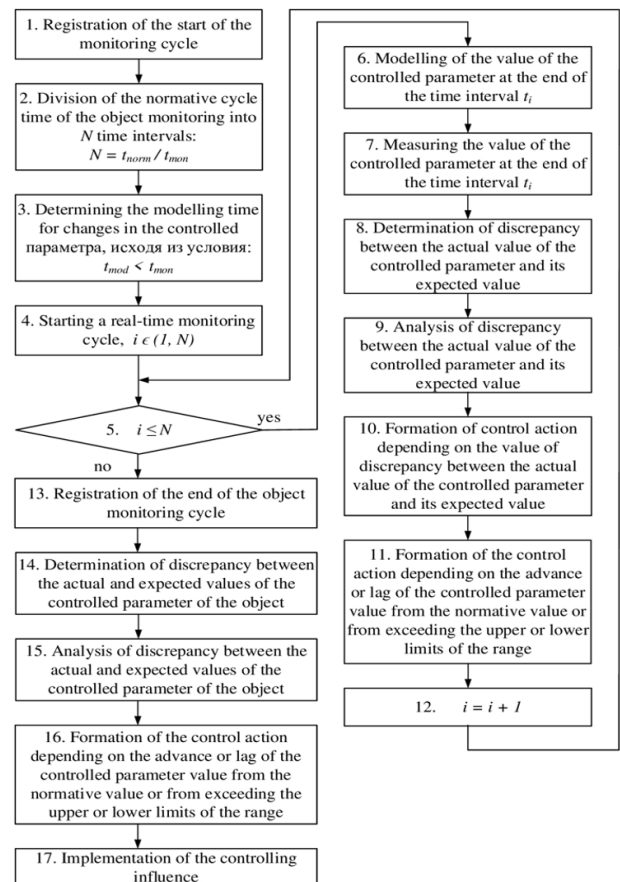


Fig. 3. Diagram of the algorithm for automated control of the object state

In existing systems, the condition of the facility is monitored as follows (see Figure 4, line 1).

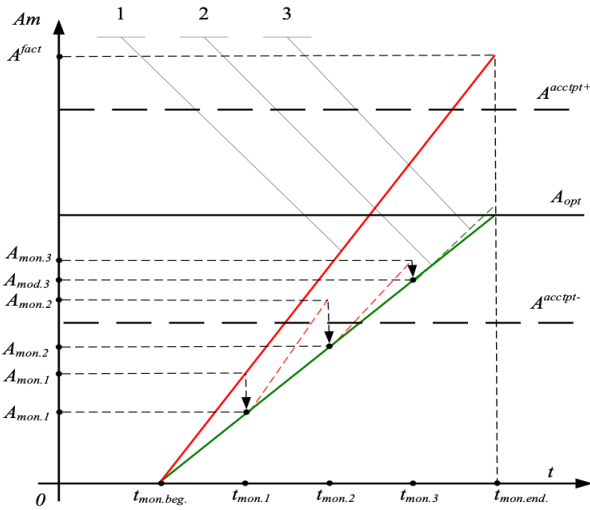


Fig. 4. Time diagrams of controlled parameter change: 1 – without correction, 2 – optimal, 3 – with correction during monitoring.

The set of expected value of controlled parameter object (A_{opt}) has a range of acceptable values ($A_{accept-}$; $A_{accept+}$).

The program start of monitoring cycle ($t_{mon.beg}$), wait for end of monitoring cycle, register its end ($t_{mon.end}$).

The value of controlled parameter (A_{fact}) is measured. The mismatch of measured and expected values of controlled parameter is determined; mismatch of values of controlled parameter is analyzed; control action is formed; corrective state of object is performed.

The disadvantage of this approach is inability to adjust parameters of object in real time, during a monitoring cycle, equal to ($t_{mon.end} - t_{mon.beg}$). Adjustments are carried out, at best, in next monitoring cycle, and more often after one or more cycles.

For fast-moving processes in monitoring facility, this is unacceptable and can be fraught with tragic consequences.

The essence of method proposed by authors is as follows (see Figure 4, lines 2 and 3).

To improve quality of real-time monitoring of objects and promptly correct condition of object: monitoring cycle time t_{norm} is divided into N time intervals ($t_{mon.1}$, $t_{mon.2}$, ..., $t_{mon.N}$) according to formula:

$$N = \frac{t_{norm}}{t_{mon}}, \quad (2)$$

where t_{norm} is standard time of monitoring cycle of object, t_{mon} is time interval for monitoring object.

At end of each monitoring time interval ($t_{mon.i}$), value of monitored parameter ($A_{mon.i}$) is measured and compared with its model value ($A_{mod.i}$).

The model value is calculated using a mathematical model of object, while simulation time for changing value of controlled parameter is set so that it is less than time interval for monitoring object and condition $t_{mod} < t_{mon.i}$ is fulfilled, so that by end of $t_{mon.i}$ there is a model value of controlled parameter to determine mismatch.

During comparison of measured ($A_{mon.i}$) and model ($A_{mod.i}$) values of controlled parameter, a mismatch is determined, on basis of which a control action is formed and

carried out, without waiting for end of current monitoring interval $t_{mon.i}$. And thus, by end of standard time of monitoring cycle of object t_{mon} , mismatch between actual value of controlled parameter and its expected value is either minimal or absent.

The analysis of mismatch of actual parameter value with expected parameter value allows you to form and implement a control effect depending on magnitude of mismatch of actual parameter value with expected parameter value.

The method proposed by authors makes it possible to detect a mismatch of actual parameter value in current control cycle and exert a control effect until its end, at each of intervals $t_{mon.i}$.

III. RESULTS AND DISCUSSION

A. Example of control of human body parameters

Cardiovascular disease is common in people worldwide. Among the most common are arterial hypertension and various forms of coronary heart disease, and in 50% of cases these diseases are comorbid. In the treatment of cardiovascular diseases, among other drugs, calcium antagonists are isolated as drugs successfully used to treat both diseases.

"Normodipine" is a drug that is a third-generation calcium channel antagonist of the dihydropyridine series, blocks slow calcium channels (L-type channels) and prevents intracellular hypercalcemia and contraction of the smooth muscle cell, having a vasodilatory effect. "Normodipine" has a long effect, which allows it to be used once a day. The course of administration is 2-12 weeks. The drug has a dose-dependent effect on the level of blood pressure and is characterized by a linear dose-concentration relationship in blood plasma. The drug is excreted from the human body with decay products. The elimination half-life of Normodipine is 35 - 50 hours. But with impaired liver function, the elimination time of Normodipine increases, which leads to its accumulation in the patient's body and a sharper decrease in blood pressure with the possible development of reflex tachycardia and excessive peripheral vasodilation (the risk of severe and persistent arterial hypotension, including shock and death) while maintaining the initial amount of the drug taken [11, 12].

Therefore, according to the authors, when taking this drug, automated control of the patient's blood pressure level is necessary in order to adjust the dose of the drug in time and get the necessary positive effect.

For automated monitoring and control of the patient's condition in this case, a device with a blood pressure monitoring function (m - Health - smart watch or tonometer) is required, included in the automated system for remote monitoring of human health (see Fig. 1).

According to algorithm shown in Figure 3, monitoring cycle, equal to duration of course of taking drug, begins with registration of beginning of monitoring process, in this case, changes in blood pressure. After that, monitoring interval (t_{norm}) is divided into N time intervals according to formula (2). For this monitoring object, we select (t_{norm}) duration of monitoring interval equal to 1 day, that is, frequency of taking drug.

We determine simulation time for changes in blood pressure as a result of taking 1 dose of drug so that $t_{mod} < t_{mon.i}$, and begin blood pressure monitoring cycle in real time.

If monitoring cycle is carried out without automated correction of blood pressure level (see Figure 4, Line 1), then by end of it we can get value of controlled parameter that does not meet our requirements – more or less than desired optimal value (A_{opt}).

When making a correction during monitoring, value of controlled parameter is determined at points $t_{mon.i}$ (in our case, 2 hours after taking drug daily) and based on monitoring results, a decision is made to change dose of drug next day. According to data [11, 12], with a single intake of 4.8 mg of drug, blood pressure decreased by 5 mmHg.

Steps 6-12 are repeated for each monitoring interval after daily dosing. And by performing these iterations for all control points $T_{(mon.i)}$, we achieve a human condition characterized either by an optimal blood pressure value for him or close to him.

B. Example of environmental control parameters control

As an example of the implementation of the proposed method for automated control of environmental parameters, we will consider its application to control the process of mobile monitoring of the territory of an urban agglomeration using an unmanned aircraft.

For this type of monitoring, an unmanned helicopter-type aircraft is used. The key factor in its use for the purposes of mobile monitoring of the territory of the urban agglomeration is that they can significantly reduce operating costs. Large areas and the need to perform many dangerous technological operations for humans make an unmanned aircraft an ideal tool for measuring the concentration of pollutants from stationary emission sources located on the roofs of buildings, often high-rise.

Unmanned aircraft are most often quadcopters equipped with portable computers, transceivers, video and/or cameras, a weather station, semiconductor sensors for measuring concentrations of chemicals. The total load on such unmanned aircraft (including batteries) can be up to 20 kg, for example, the T-DRONES MX860 BVS, which has technical characteristics: maximum take-off weight: 19.96 kg, maximum ascent speed: 5 m/s, maximum descent speed: 3 m/s, maximum horizontal speed: 20 m/s.

When using an unmanned aircraft for mobile monitoring of the territory of an urban agglomeration, the operator enters initial data from the control panel into his laptop computer to complete the task.

This data includes:

- work location (electronic map of the territory of the urban agglomeration with geometries),
- route and trajectory in the given square (in the given example, the trajectory "meander" - green line in Figure 5),
- number and coordinates of control points,
- speed of movement along the monitoring route.

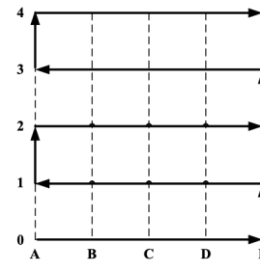


Fig. 5. Trajectory of an unmanned aircraft when monitoring the territory of the urban agglomeration

That is, the operator causes the unmanned aircraft to travel along a predetermined path (m) at a predetermined speed (m/s) and to measure concentrations at a predetermined frequency (times/hour) so that all reference points marked with geotags are passed at a predetermined time.

In real situations, an unmanned aircraft can be influenced by weather conditions (wind, humidity, etc.) by increasing or decreasing its speed. The result of this will be the possibility of leaving the route, earlier or late arrival at the point of control (measurement). This will lead to unreliability of the results obtained. Therefore, there is a need for automated control of mobile monitoring of the territory of the urban agglomeration. The monitored parameter is the distance flown by the unmanned aircraft over a time interval.

Automatic control of mobile monitoring of the territory of the urban agglomeration is carried out as follows.

Registers the beginning of the monitoring route when the operator downloads the process card data to the portable computer of the unmanned aircraft and launches the unmanned aircraft.

The standard time of movement of an unmanned aircraft to the first control point is divided by its portable computer into N time intervals.

By managing mobile monitoring of the urban agglomeration territory, a portable computer of an unmanned aircraft, knowing the standard time T_{norm} during which it must reach the control point where it will take measurements, and the time interval for monitoring the technological process T_{mon} divides T_{norm} into N time intervals (control points) according to formula (2), indicating on the electronic map at what point the unmanned aircraft should be at each time $t_{(mon.i)}$.

That is, with the behavior of mobile monitoring of the territory of the urban agglomeration, an unmanned aircraft moving along the trajectory of the "meander" must overcome the distance from the A_m point to the D_m point during the T_{norm} . This time is set in the routing.

For example, the A-D distance is 600 m. Moving at a speed of 1 m/s in ideal conditions, an unmanned aircraft will reach point D in $600 s = 10$ minutes. This is the standard time (T_{norm}) of one flight. Setting the monitoring time (T_{mon}) every 2.5 minutes, we obtain four control points after 2.5 using formula (2); 5; 7.5 and 10 minutes from the start of monitoring.

Portable computer of unmanned aircraft determines time of simulation of process parameter change based on T_{mod} condition $< T_{mon}$.

The portable computer of the unmanned aircraft sets the simulation time (T_{mod}) of its arrival at each of the control

points, taking into account the real flight conditions, so that you can have time to fly to the control point on time.

For example, given a T_{mod} condition $< T_{mon}$, sets the simulation time to 1 minute from the start of the time interval. During this time, an unmanned aircraft will be able to fly a certain distance and record it and environmental parameters.

A portable computer of an unmanned aircraft begins a cycle of real-time monitoring of the values of technological process parameters, i (1, N).

For example, flying out of the A0 point and moving in the direction of the point D0 an unmanned aircraft monitors parameter (environmental parameters, speed and time of approach to the monitoring point), checking if it has gone beyond the controlled area.

Having determined that the unmanned aircraft has not left the trajectory, that is, $i \leq 4$, the laptop computer begins a cycle of real-time control of the values of the process parameters (environmental parameters, speed and time of approach to the monitoring point).

The cycle starts by simulating the time of approach to the control point B0 taking into account the environmental parameters (temperature, humidity, wind speed and direction) ($T \pmod{1}$).

For example, the calculation established that, taking into account environmental parameters, an unmanned aircraft will arrive at the B0 point in 2 minutes 7 seconds (tailwind).

At approach to check point time of approach to check point B0 is measured ($t \pmod{1}$).

For example, it is 2 minutes 30 seconds.

Comparing the simulation result of the time of approach to the control point B0 the mismatch of the actual ($T \pmod{1}$) and expected ($T \pmod{1}$) time of occurrence of the ASU at the control point of the B0 is determined.

For example, $t \pmod{1} - t \pmod{1} = 2 \text{ minutes } 7 \text{ seconds} - 2 \text{ minutes } 30 \text{ seconds} = -23 \text{ seconds}$.

In the presence of such a mismatch, it determines its nature (lead or lag).

For example, an unmanned aircraft arrived at a control point B0 23 seconds earlier.

Based on the analysis results, generates a control action depending on the mismatch value and its sign (advance or lag).

For example, the laptop computer generates a control action that reduces the speed of the unmanned aircraft.

The unmanned aircraft takes a course to the next control point and if condition $i \leq 4$ is met, it flies directly to the next point and operations 6 - 12 (see Fig. 3) are repeated for it and so on to the control point D_0 .

After the D_0 checkpoint, the counter $i = i + 1$ shows the value $i > 4$ and the laptop computer registers the end of the analyzed process.

The laptop determines the mismatch between the actual and expected process times over the entire t_{norm} time interval.

For example, the entire workflow should end in 10 minutes, and it ended in 10 minutes 15 seconds.

There is an analysis of the time of mismatch of the technological process.

For example, 15 seconds behind schedule. Based on the analysis results, generates a control action depending on the mismatch value and its sign (advance or lag).

For example, a portable computer of an unmanned aircraft generates a control action that increases the speed of the unmanned aircraft so as to compensate for the late approach and the next monitoring cycle to start on schedule.

Performs control action depending on the advance or lag time of the monitoring process.

IV. CONCLUSIONS

Thus, in the method according to the present invention, it is possible to correct the state of a monitoring object in real time by controlling a parameter during a process, thereby improving the efficiency of the processes.

The technical result is the ability to monitor the technological process by various parameters (including time), taking into account the requirements of regulatory documents using monitoring sensors.

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Improving Quality of Stress Assessment Based on Analysis of Signs of Takotsubo Syndrome

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Abstract — The article substantiates need improve quality of assessment of stress levels in humans based on analysis of signs of Takotsubo syndrome. analyze methods of diagnosis and assessment of stress levels and Takotsubo syndrome. relationship between stress level assessment parameters using "Spielberger-Khanin Anxiety Scale" and emotional and physical stress according "InterTAK Takotsubo Syndrome Risk Stratification Scale" has been established. algorithm for diagnosing Takotsubo syndrome using Spielberger-Khanin Anxiety Scale has been improved.

Keywords — social network user, stress, anxiety level, takotsubo syndrome, neural networks; information processing models, Big Data mining, convolutional neural networks.

I. INTRODUCTION

Stress is an integral part of modern life, affecting human health and quality of life. Therefore, problem of diagnosis, assessment and management of stress levels is becoming more urgent.

Currently, Russia has declared an unspoken "information and psychological war" (disinformation. telephone fraud and cyber bullying, etc.), during which citizens suffer significant moral (stress, nervous disorders, disruption of nervous and cardiovascular systems of body) and material (losing their savings and borrowed funds) damages, contributing occurrence of stressful conditions in people. Experts identify following groups of factors that have come fore and form and exacerbate stressful conditions in people in modern world: digital overload, work-life imbalance, economic problems, and social expectations. And as a limiting situation in humans, changes in parameters of vital activity occur, leading a violation of regime of work and rest, nutrition, and as a result a violation of human health. In most cases, moral and material damage leads uncontrolled, and in some cases, unconscious stress.

With uncontrolled stress, a person experiences physiological (suppression of immune system, cardiovascular problems, digestive problems, endocrine system disorders, weight gain, sleep disorders, etc.) and psychological (mood disorders, cognitive impairments, emotional exhaustion, etc.) effects leading poor health.

To minimize and eliminate occurrence of such effects, methods for determining and assessing stress levels have been developed all over world since 50s of 20th century. This is necessary choose optimal stress management strategy.

The aim of work is improving algorithm for diagnosing takotsubo syndrome using "Spielberger–Hanin Anxiety Scale" and thereby improve quality of diagnosis and assessment of stress levels.

Tasks:

- analyze methods of diagnosis and assessment of stress levels and takotsubo syndrome;
- establish a relationship between parameters of stress assessment using "Spielberger-Hanin Anxiety Scale" and emotional and physical stress according "InterTAK Takotsubo Syndrome Risk Stratification Scale";
- improve algorithm for diagnosing takotsubo syndrome using "Spielberger-Hanin Anxiety Scale".

II. MATERIALS AND METHODS

A. Existing methods for diagnosing and assessing stress levels

For rapid stress diagnosis, a number of oral scales and questionnaires are used determine levels of anxiety and depression. Among specialized tests, first of all, lusher test and Hamilton scale should be highlighted [1].

The Tsung scale is used for self-assessment of depressive states, screening diagnostics in mass studies, and for purpose of preliminary and pre-medical diagnosis of stress [2]. disadvantage of these methods of stress diagnosis and assessment is low reliability of results obtained and inability dynamically monitor subject.

In clinical psychology, assess level of anxiety and determine impact of stress on a person, "Spielberger-Khanin Anxiety Scale" is used, which makes it possible distinguish temporary anxiety caused by a situation (situational anxiety) occurring with a person from chronic anxiety associated with personality traits (personal anxiety). essence of this technique is conducting a human examination by testing using two blocks of questions. first set of questions evaluates indicators of situational anxiety, that is, anxiety that is caused by a given moment in time, and is characterized by tension, anxiety and nervousness in a specific situation. second is indicators of personal anxiety, that is, individual property of body perceives events as threatening and react them.

The assessment of a person's condition is carried out after analyzing test results and scoring points. total final score for each of blocks is in range from 20 80 points, and higher final score, higher level of anxiety, and subsequently stress: up 30 points – low anxiety, from 31 44 points – moderate anxiety, more than 45 points – high anxiety [3].

The most effective methods of assessing psychoemotional stress are objective methods that do not depend on opinion of subject. For example, electrobioluminescent [4].

Proven and effective methods for diagnosing and assessing human stress levels are methods in which electrophysiological parameters of a person are widely used, for example, electrocardiography (ECG), a method for recording potential difference of electric field of heart that occurs during its operation.

Many researchers have established and confirmed relationship between stress and state of cardiovascular system. Moreover, state of cardiovascular system is both a victim and an indicator of stress levels. They identify heart rate (HR) (f, 1/min) and blood pressure (BP, mmHg) as most stress-dependent parameters.

A group of researchers proposed a method [5] for determining stress levels, consisting in simultaneous measurement of heart rate and blood pressure, followed by calculation of double product (DP):

$$DP = 0,01 \cdot f \cdot SBP, \quad (1)$$

where SBP is systolic blood pressure.

There is a method for assessing functional state of cardiovascular system [5] based on measuring blood pressure parameters, recording a sphygmogram during one respiratory cycle, determining duration of average value of one cardiac cycle (T, ms), and measuring rise time of pulse blood pressure (t, ms).

The severity of functional stress (S, conl. units) is determined at $t < 155$ ms:

$$S = \frac{23,6 \cdot PBP \cdot DBP}{(T \cdot (0,001 \cdot PBP + 0,9591) - 5)} \quad (2)$$

and at $t > 155$ ms:

$$S = \frac{22,9 \cdot PBP \cdot DBP \cdot (0,007 \cdot PBP + 0,6892)}{(T - 41)} \quad (3)$$

where PBP and DBP are pulse and diastolic blood pressure, respectively.

This method is characterized by complexity associated with registration of sphygmogram and complexity of processing its parameters, as well as absence of individual differences in blood pressure and heart rate used determine stress levels.

Another way determine stress levels includes measuring heart rate and pulse blood pressure, body weight (M), and determining stress levels using formula:

$$S = f \cdot PBP \cdot M^{1/3} \cdot K \quad (4)$$

where S is stress level; K is coefficient equal 0.8244×10^{-4} for men and 0.9357×10^{-4} for women.

There is a method for determining stress levels based on recording human vegetative parameters: respiratory rate (HR), heart rate, and galvanic skin resistance. Based on this,

a cross-correlation coefficient is obtained, which determines degree of stress development [6].

In addition, various stress detection methods, there are contact methods and measurement systems for determining a person's stress level. obtain general psycho-emotional information about a person, physiological parameters of human body are used. For example, digital heart rate analyzers Omega M, Omega-S and Lotus, designed study functional state of patient. It is based on a neurodynamic analysis of heart rate variability [4].

The Inferum company (Yekaterinburg, Russia) has proposed ROFES-E01C hardware and software package, a registrar for assessing functional and emotional state, which is designed for individual comprehensive diagnostics of body. This complex is designed test and monitor functional state of 17 major organs and systems of body, as well as assess a person's psychoemotional state (fatigue, stress, effect of emotions on body). test and control method is based on exposure biologically active point MS-7, located on inside of left wrist, through which a microcurrent pulse is sent all organs, causing a response. In humans, each organ works in a strictly defined, inherent rhythm. responses of these rhythms are returned back device, and then compared in program with reference rhythms that are characteristic of body of a healthy person of appropriate gender and age [7].

The need determine a person's stress level is caused by fact that it has a negative impact on various organs and systems of human body, causing malaise, development of diseases and disruption of well-coordinated functioning of body.

B. Takotsubo syndrome

One of most common disorders of human body under influence of stress is takotsubo syndrome.

Takotsubo syndrome is an acute disease of heart muscle that often develops as a result of stress. danger of this disease is caused by fact that symptoms resemble an acute myocardial infarction: there is a sharp pronounced pain behind sternum, which does not weaken from taking painkillers and radiates left arm, lower jaw and interscapular space. temperature rises $37.3-38.5^{\circ}C$, cold and sticky sweat may appear, fear of death, shortness of breath at rest and with slightest exertion. In some cases, heart rhythm is disrupted, and patient may die [8, 9].

Takotsubo syndrome was first described by Japanese physician Sato in 1990. He and a group of co-authors used ultrasound find that in first hours of disease's development, heart has shape of a balloon due expansion and weak contractility in apex area (Fig. 1).

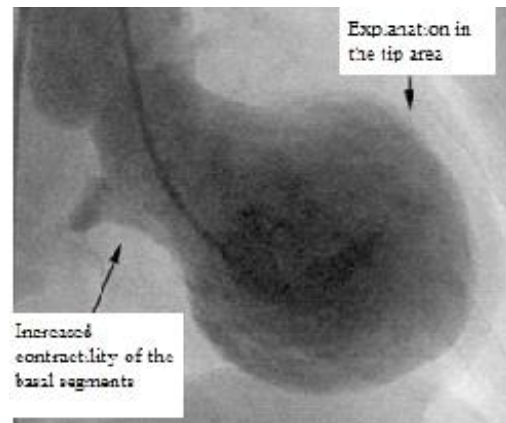


Fig. 1. Heart in takotsubo syndrome [9].

The development of disease occurs due a sharp increase in level of stress hormones and spasms of blood vessels feeding heart. As a result, vascular resistance increases at moment of cardiac output and load on heart muscle (myocardium) increases.

The causative factors of development of takotsubo syndrome may be psychoemotional factors (quarrels, living for loved ones, emergencies, financial difficulties, etc.) and physical factors (anemia due gastrointestinal bleeding; overdose with insulin and beta-adrenomimetics; surgery and general anesthesia; severe illness; reaction alcohol or opiate withdrawal; use of drugs, etc.) [10, 11].

The mechanisms underlying development of takotsubo syndrome include sudden, excessive release of catecholamines in combination with increased sensitivity of cardiomyocytes and microcircular bed of heart muscle catecholamines with development of prolonged but reversible left ventricular dysfunction [9].

Thus, due high similarity of symptoms of takotsubo syndrome with symptoms of myocardial infarction, it is necessary correctly diagnose patient at initial stages of determining disease.

A committee of experts from European Society of Cardiology has proposed an algorithm for diagnosing a patient who was admitted emergency department with complaints of chest pain and/or shortness of breath detect takotsubo syndrome. This algorithm includes use of InterTAK takotsubo syndrome risk stratification scale (Table. 1) and conducting diagnostic examinations of patient [12].

TABLE. I. INTERTAK TAKOTSUBO SYNDROME RISK STRATIFICATION SCALE

Criterion	Number of points
Female gender	25
Emotional stress	24
Physical stress	13
Absence of ST depression on ECG	12
Mental disorders	11
Neurological disorders	9
QT prolongation on ECG	6

According InterTAK takotsubo syndrome risk stratification scale, prognostically significant clinical criteria are: female gender, presence of a previous emotional or physical trigger, absence of ST-segment depression, presence of mental or neurological disorders, and prolongation of QT interval. presence of each of these criteria determines amount of points received according a scale with a maximum of 100 points [13, 14] (see Figure 2).

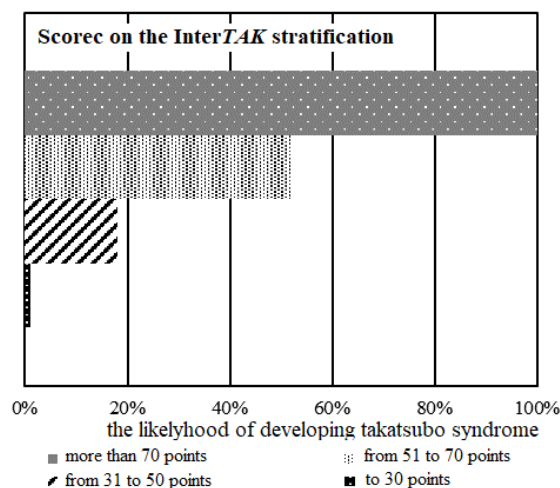


Fig. 2. Probability of developing takotsubo syndrome on InterTAK risk stratification scale

Thus, patients with a final score of up 30 points on InterTAK stratification scale have a predicted minimum probability of developing takotsubo syndrome (less than 1%), patients who scored from 31 50 points during examination have a low (18%), if patient has a final score of 51 70 points, probability of developing takotsubo syndrome is high. – in almost half of cases (52%), and in patients with scores of 70 or more, takotsubo syndrome may be diagnosed with a maximum probability (more than 90%), rather than diseases of cardiovascular system [13, 14].

III. RESULTS AND DISCUSSION

If patient has initial symptoms: burning, baking and pressing chest pain radiating left arm, lower jaw and interscapular space, as well as shortness of breath and possible fainting, he should immediately consult a doctor determine causes of this condition and make a diagnosis. And it is important for a doctor make a correct diagnosis in order prescribe an effective treatment regimen.

Since these symptoms may indicate both myocardial infarction and takotsubo syndrome, authors propose an improved algorithm [13, 14] for conducting a patient examination make a diagnosis (Fig. 3) and based on an analysis of signs of takotsubo syndrome.

Improving quality of stress assessment is expected be achieved by assessing emotional and physical stress on "Spielberger-Khanin Anxiety Scale."

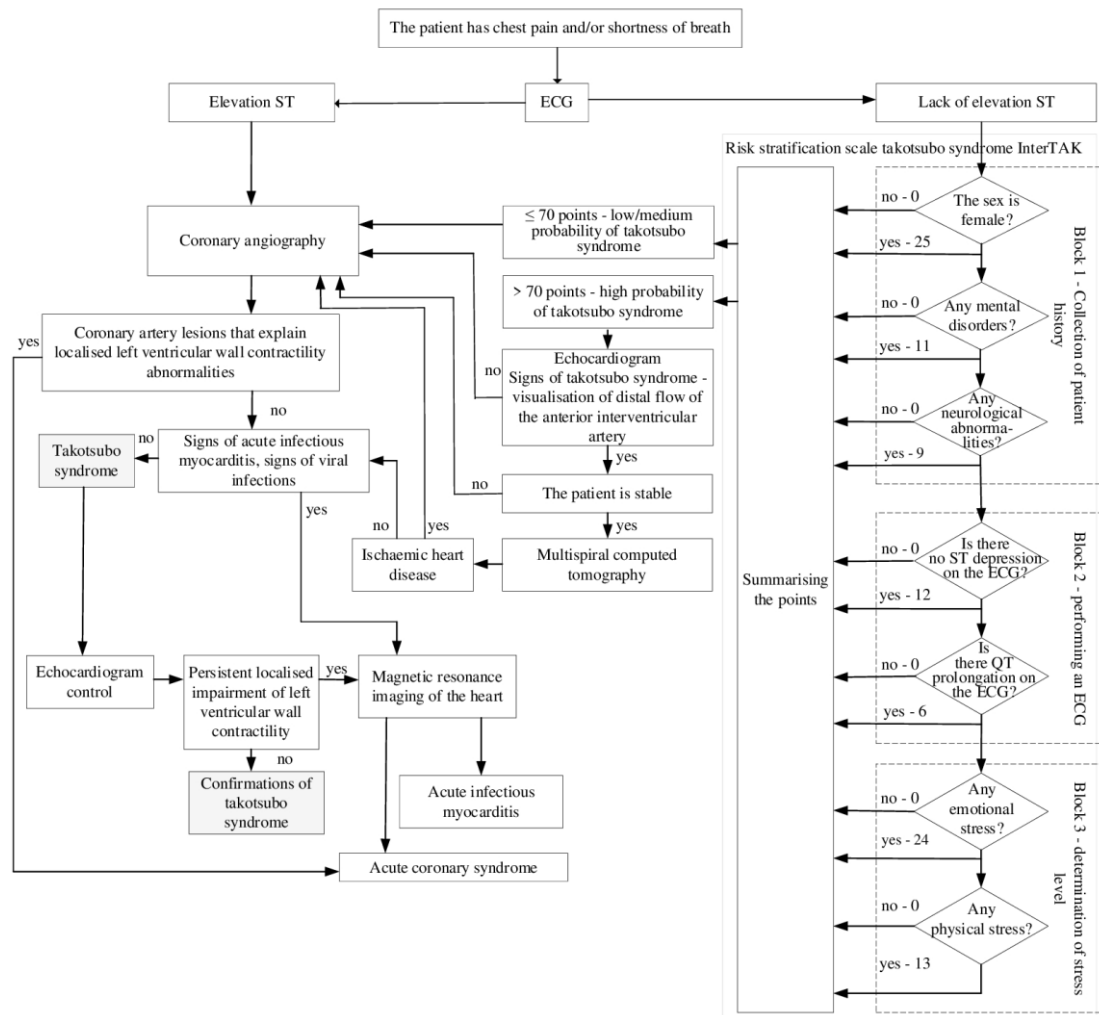


Fig. 3. Algorithm for diagnosis of takotsubo syndrome

When a patient visits a medical institution, doctor must collect a clinical analysis of patient (block 1) based on "InterTAK Takotsubo Syndrome Risk Stratification Scale" [13].

Since patient complains of chest pain, it is necessary conduct an examination, first of all take an ECG detect ST segment depression and prolongation of QT interval (block 2).

Then, in order identify level and impact of stress on patient's condition, it is necessary determine level of emotional and physical stress (block 3).

The authors propose use "Spielberger-Khanin Anxiety Scale" for this purpose, which allows us identify a person's stress level depending on impact of stressful situations and life shocks on human cardiovascular system.

Considering that according Spielberger-Khanin, emotional stress is associated with personal anxiety, and physical stress is associated with situational anxiety, assessing patient's condition on this scale provides reliable results that can be used assess stress on "Takotsubo InterTAK Syndrome Risk Stratification Scale." Thus, presence of emotional and physical stress in accordance with [14] corresponds high anxiety (more than 45 points) according Spielberger-Khanin [3]. And in this situation, patient receives 24 and 13 points for presence of emotional and physical stress, respectively. In absence of such testing results or if doctor focuses on state of cardiovascular system, it is possible receive negative responses in block 3 and, in

accordance with Figure 3, doctor does not respond takotsubo syndrome, diagnoses a disease of cardiovascular system, prescribes a treatment regimen for this disease, implementation of which does not lead relief of patient's condition. And even vice versa, condition deepens with an increase in stress.

Therefore, when conducting an initial analysis of patient's condition, it is necessary assess contribution of stress formation of patient's condition by calculating appropriate points, summarizing points obtained and carrying out further examination of patient according algorithm shown in Figure 3.

If a patient scores less than 70 points on "InterTAK Takotsubo Syndrome Risk Stratification Scale", which characterizes a low probability of takotsubo syndrome, then patient is sent for coronary angiography detect damage coronary arteries, which explains local contractility disorders of walls of left ventricle. If there are no signs of damage coronary arteries, then an examination is carried out for signs of viral infections, in their absence, a preliminary diagnosis of takotsubo syndrome is made. confirm diagnosis, echocardiogram monitoring is performed and, if no persistent violation of contractility of walls of left ventricle is detected, diagnosis of takotsubo syndrome is confirmed.

If a patient scores more than 70 points on "InterTAK Takotsubo Syndrome Risk Stratification Scale", this indicates a high probability of diagnosis of takotsubo syndrome, therefore, an echocardiogram should be prescribed. If

examination does not reveal signs of takotsubo syndrome (visualization of distal flow of anterior interventricular artery), then patient is sent for coronary angiography and further studies are performed according same principle as in first case. If signs of takotsubo syndrome are detected on echocardiogram, it is determined whether patient is stable and, if positive, a multispiral computed tomography is performed exclude coronary heart disease. If this diagnosis is not confirmed, signs of viral infections are determined and, in their absence, takotsubo syndrome is preliminarily diagnosed, and then it is confirmed in same way as in first case.

Thus, this algorithm helps distinguish takotsubo syndrome from other diseases of cardiovascular system (coronary artery disease, acute infectious myocardium, acute coronary syndrome) in a patient who arrives at a medical facility and allows for high-quality treatment of patient. Since in treatment of takotsubo syndrome it is necessary simultaneously carry out symptomatic and etiotropic treatment, which will be aimed at cause and manifestation of disease, that is, treatment takes place in several stages, first takotsubo syndrome is treated as acute coronary syndrome and alleviate physical condition of patient, after which it is necessary treat psychoemotional state of patient, since cause of takotsubo syndrome These are psychoemotional and physical factors that affect human health.

Therefore, it is necessary qualitatively assess psychoemotional state of a person in order identify stress exerted on him and assess effect of his body on him.

IV. CONCLUSIONS

The conducted studies clearly demonstrated that in order to improve the quality of diagnosis and assessment of a patient's cardiovascular system, it is necessary to have a tool that can differentiate the causes of the disease.

The algorithm proposed by the authors, as a tool for such differentiation, allows for the identification of changes in the patient's cardiovascular system related to increased stress levels, even when the symptoms are similar, and provides data for appropriate treatment. The use of the proposed algorithm increases the quality of myocardial infarction diagnosis by 1-2% due to the exclusion of Takotsubo syndrome, and in 90% of older women by 7-10% [8, 11, 12].

Given the importance of stress level accounting and assessment in the diagnosis of cardiovascular diseases, further research and development and practical

implementation of software and hardware based on the proposed algorithm for the diagnosis of Takotsubo syndrome.

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Smart Quality Management System of a Digital Enterprise Based on Neural Networks

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Abstract—The article presents an intelligent quality management system of a digital enterprise based on self-learning neural networks for the design of oil product pipelines. The system combines deep learning methods with physics-informed neural network models, which makes it possible to optimize pipeline parameters in real time, predict emergency situations and adapt to changing operating conditions. The proposed approach demonstrates a 30-40% increase in the accuracy of calculations compared to traditional methods while reducing the time spent on design.

Keywords—self-learning neural networks, pipeline design, quality management system, physics-informed machine learning, Six Sigma.

I. INTRODUCTION

Modern pipeline design faces three fundamental challenges:

- 1) *Complex multiphysical processes.* Hydraulic shocks, pressure drops.
- 2) *High-dimensional optimization.* Optimization of material costs, selection of materials, tracing.
- 3) *Dynamic operating conditions.* Consideration of environmental factors.

Traditional design systems are based on:

- 1) *Complex computational models.* High computational complexity and costs when CFD (Computational Fluid Dynamics) — modeling.
- 2) *Empirical standards.* Excessive conservatism and inability to quickly adapt to new data.
- 3) *Manual control.* Error tolerance and limited forecasting capabilities for complex nonlinear processes.

The proposed solution based on self-learning neural networks eliminates these disadvantages by providing:

- Self-learning neural networks based on new data.
- Digital doubles for continuous verification.
- Automated quality metrics in the Six Sigma paradigm.

II. RELEVANCE

Currently, there is no optimal solution on the market for simultaneous automation of hydraulic calculations in the stationary mode of pumping oil and petroleum products, and the design of main oil product pipelines with two or more branches.

III. PREREQUISITES FOR CREATING AN INTELLIGENT QUALITY MANAGEMENT SYSTEM OF A DIGITAL ENTERPRISE BASED ON NEURAL NETWORK APPROACH

The design of main pipelines is a complex and time-consuming job that requires a lot of time, knowledge and detailed calculations. The prerequisites for the study of this idea and its automation were the huge number of calculations performed and their special category of complexity, the search for optimal solutions, including: minimizing labor costs for calculations, improving the quality of design work, reducing data processing time, and assigning tasks to design and estimate departments.

Much attention is paid to the design of measures when the pipeline crosses natural (ravines, hills, water barriers) and artificial (highways and railways) structures, it is this process that can increase the design process tenfold.

IV. ARCHITECTURE OF AN INTELLIGENT QUALITY MANAGEMENT SYSTEM OF A DIGITAL ENTERPRISE BASED ON A NEURAL NETWORK APPROACH

The architecture includes three levels:

- 1) *Data level.* Data collection and enrichment module:

- IoT (Internet of Things) — real-time sensors (pressure, flow rate, temperature).
- Historical data of SCADA (Supervisory Control and Data Acquisition) systems. They contain the key parameters of pipelines for 10 years.
- Satellite data on terrain and geology.
- Aerial laser scanning data.
- The results of laboratory tests of materials. Integration with digital twins will allow you to predict the degradation of materials.

- 2) *Self-learning neural network layer.* Hybrid neural network models:

- PINN (Physics-Informed Neural Networks) — hybrid neural network models hybrid method that combines neural networks and physical laws to model complex dynamical systems, including hydrodynamic problems Hybrid method that combines neural networks and physical laws to model complex dynamical systems, including hydrodynamic problems.

- GAN (Generative Adversarial Network) — a deep learning method used to identify anomalies and defects in materials based on comparing two neural networks with real data and generated ones. Suitable for water hammer simulation.

- GNN (Graph Neural Network) —a class of neural networks designed to process data represented as graphs. They are able to take into account the connections between objects, which makes them indispensable for tasks where not only information about nodes is important, but also the structure of their interactions.

- DEEP RL (Deep Reinforcement Learning with Reinforcement Learning) — a method of training highly loaded neural networks. It is used to optimize the pipeline route based on terrain and geological data.

3) *The level of quality management of a digital enterprise of a digital enterprise and decision-making.*

- Six Sigma dynamic control cards. The use of adaptive algorithms — automatic recalculation of boundaries during: technological regime changes, material changes, scheduled stops.

- Automated FMEA (Failure Mode and Effects Analysis) analysis of complex systems of pipeline components. Reduces the risk of pipeline accidents, while reducing maintenance costs.

- A generator of corrective actions. Reduces the response time. It is necessary to introduce industrial IoT and integrate with monitoring systems.

V. SELF-LEARNING MECHANISMS OF INTELLIGENT NEURAL NETWORKS

1) *Active learning.* An approach in which an intelligent neural network chooses which data it needs to use to maximize its accuracy.

2) *Knowledge transfer mechanism.* An approach that uses pre-trained models for new sites.

3) *Adaptive regulation.* An approach in which the parameters of the training system automatically select optimal performance for themselves in a changing environment. The balance between accuracy and speed.

Self-learning mechanisms allow you to:

- 1) *Automatically adapt to changes in industrial systems.*
- 2) *Reduce maintenance costs.*
- 3) *Increase diagnostic accuracy.*

VI. PRACTICAL IMPLEMENTATION USING THE EXAMPLE OF DESIGNING AN OIL PIPELINE SECTION IN A ZONE OF HAZARDOUS GEOLOGICAL PROCESSES

It is necessary to design a stable pipeline route in an area with landslides, karsts or seismic activity.

The scenario includes:

1) *Primary analysis.* Uploading geological data (satellite data obtained by aerial laser scanning) [1]. Load forecasting using the GNN neural network for terrain triangulation.

2) *Risk analysis.* Identification of areas with high soil deformation [2, 3].

3) *Route selection.* Construction of a three-dimensional model taking into account geomechanical constraints. Practice shows that the most optimal route is to avoid areas with dangerous geological processes.

4) *Optimization of parameters.* Selection of materials using the RL neural network, calculation of the optimal pipe

diameter for each section of the pipeline, calculation of the optimal pipe wall thickness for each section of the pipeline.

5) *Continuous monitoring.* Correction of models based on sensor data in order to predict the wear of both the whole pipe and its component.

VII. PRACTICAL IMPLEMENTATION USING THE EXAMPLE OF DESIGNING AN OIL PIPELINE WITH TWO OR MORE BRANCHES

It is necessary to obtain the best option for laying the pipeline, taking into account the cost of the pipe material, as soon as possible under the specified conditions.

The scenario includes:

1) *Primary analysis.* Uploading geological data (satellite data obtained by aerial laser scanning) [1]. Load forecasting using the GNN neural network for terrain triangulation.

2) *Risk analysis of hazardous geological processes.* Identification of areas with high soil deformation [2, 3].

3) *Route selection.* Construction of a three-dimensional model taking into account geomechanical constraints from high-altitude plots.

4) *Analysis of the selected route.* Loading topological data. Re-routing, taking into account the bypass of critical areas and nature protection zones using the hybrid neural network GNN.

5) *Analysis of the chosen ways of passing natural and artificial obstacles.* Loading topological data. Choosing a drilling method using a hybrid neural network GNN [4].

6) *Optimization of material parameters.* Selection of materials using the RL neural network, calculation of the optimal pipe diameter for each section of the pipeline, calculation of the optimal pipe wall thickness for each section of the pipeline, selection of pumping equipment taking into account the volume of pumped oil and petroleum products.

7) *Optimization of engineering infrastructure usage parameters.* Selection of resources using the RL neural network, calculation of the optimal distribution of engineering equipment for each section of the pipeline, taking into account waste.

8) *Continuous monitoring.* Correction of models based on sensor data in order to predict the wear of both the whole pipe and its component.

VIII. ADVANTAGES AND PERSPECTIVES

The key advantages are:

- 1) *Speed.* Calculations in close to real-time mode.
- 2) *Accuracy.* Accounting for hundreds of parameters simultaneously.
- 3) *Reliability.* Forecasting of rare emergency events.
- 4) *Savings.* Optimization of material resources.

IX. VULNERABILITIES AND RISKS

1) *Errors in algorithms.* Complex business logics using machine learning and artificial intelligence algorithms may contain errors or be insufficiently trained. This can lead to incorrect interpretation of the data and, as a result, to incorrect business decisions..

2) *The human factor.* Errors caused by inexperience or insufficient training of employees can become a serious

vulnerability for the architecture. For example, improper use of software or careless handling of data can cause system failures..

3) *Lack of integration.* The lack of proper integration between different systems and parts of the architecture can lead to gaps in data and process management. This creates opportunities for human error and data conflicts. [5].

4) *Architecture selection.* Determining the optimal neural network architecture requires significant resources and experiments.

X. CONCLUSUIN

As a result of the creation of an intelligent quality management system of a digital enterprise based on a neural network approach, the following results have been achieved:

- 1) *Accelerate iterations of the main oil pipeline design by 62%.*
- 2) *Ensure the quality of Six Sigma.*
- 3) *Reduce the total cost by 15-30%.*

The use of neural networks in quality management of a digital enterprise opens up new opportunities for improving the efficiency and reliability of production processes.

Deep learning allows you to analyze complex data and make informed decisions, which ultimately leads to improved product quality and customer satisfaction.

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Digital Twins: Industry IT Services of Quality Management Systems

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Abstract — The article considers the features of automation of production processes and the potential for the development of specialized production automated systems in a single digital space of the enterprise based on the concept of the product life cycle. A combination of models of a digital twin of a production product and a digital twin of a production process is presented as the most promising digital model. A classification of digital twin models by functional areas is carried out and the features of the digital shadow, digital twin and digital clone models are highlighted.

Keywords — *manufacturing process, manufacturing product, product life cycle, model isomorphism, digital twin, digital shadow, digital duplicate, digital clone, software, IT services, quality management, competitiveness, digitalization.*

I. INTRODUCTION

Today, it is difficult to imagine the creation of high-tech competitive products in almost any industry without efficient production. The greatest concentration of efforts in this area is focused on the issues of enterprise digitalization and the formation of a single information space. The introduction of modern production IT services allows us to significantly speed up the entry of new product samples into the market, reduce resource consumption, and improve the quality of both finished products and the processes of their creation. The level of digitalization of an enterprise is an integral marker of its competitiveness system, by which one can assess the prospects for its further development [1,2].

Data management processes are one of the central elements of industrial automation and form the digital contour of the product competitiveness system. At the same time, new computing capabilities that have recently opened up make it possible to use those computer and mathematical models that until recently remained at the theoretical level of application when working with data [3]. Computer sciences generate new methods, models, algorithms and specialized software that make it possible to represent the properties, functions, behavior and states of production facilities, design their design and technological models, and manage the processes of their creation at a fundamentally new level of quality. The main software tool in this direction within the framework of the Industry 4.0 paradigm is the creation of digital twins [4-9] (Fig. 1).

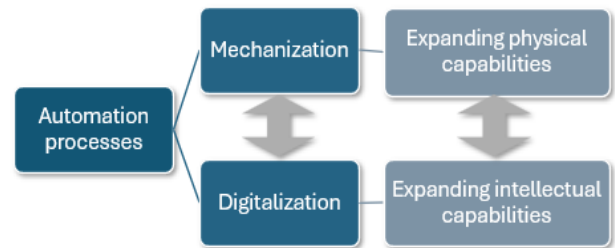


Fig. 1. Structure of industrial automation processes

Despite the obvious close relationship, automation processes can be conditionally divided into mechanization and digitalization processes. The main function of mechanized processes is to compensate for or enhance the physical capabilities of a person, which, for example, is clearly reflected in the development of a whole range of production areas related to assistive robotics or modern automated production systems. Digitalization processes are more associated with compensating or enhancing the cognitive (intellectual) capabilities of a person and stimulate the exponential growth of the use of artificial intelligence as elements of management decision-making systems in production.

For a considerable period of time, automation of production has been based on the already fundamental concept in production of the "Product Life Cycle" and supports the concept of integrated support for all stages of the production process: (PLM system - Product Lifecycle Management). As a single information space of the enterprise, this system combines a whole range of application software: CAD - Computer-Aided Design, CAE - Computer-Aided Engineering, CAM - Computer-Aided Manufacturing, MES - Manufacturing Execution System, MRP - Material Requirements Planning, ERP - Enterprise Resource Planning, PDM - Product Data Management and other solutions related to system engineering based on MBSE models - Model-based systems engineering (Fig. 2).

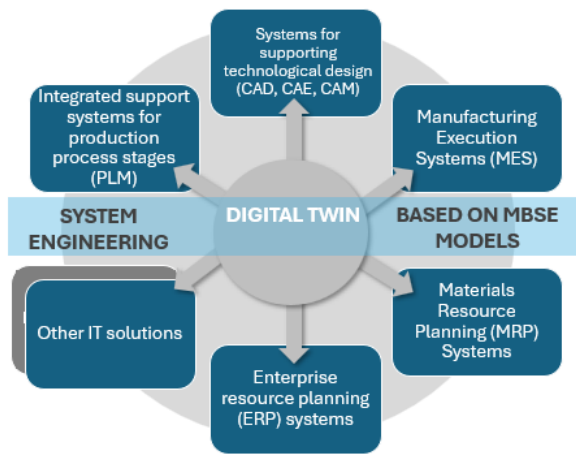


Fig. 2. Areas of distribution of digital twins in the structure of industrial automation

It can be definitely stated that if an enterprise has automated management of product data, and automated management of the main, management or service production processes, then the enterprise has certain signs of digitalization. More correctly, the question should be posed not about the presence of digitalization as such, but about the level of its development, and, as a consequence, the level of competitiveness of the enterprise.

II. DIGITAL TWIN AS AN INDUSTRY- SPECIFIC IT-SERVICE

The ongoing revolution in software development and the almost avalanche-like development and increase in the presence of AI models in a wide range of automated systems makes it possible to put forward this metric as the main control marker of evidence of the level of digital development of the enterprise. The most promising focal application of intelligent solutions in production is concentrated in the concept of "Digital Twin".

The analysis shows that despite the fact that some automated production systems assume modules for simulating real processes, most solutions do not have a "direct" connection with the physical modeling object. Therefore, it is not possible to predict the behavior, state and function of the modeling object. While, having such capabilities, it is possible to effectively solve problems of safety, increasing reliability, minimizing costs, optimizing designs, rational maintenance, etc. The development and implementation of digital twin models in the semantic models of many of the above-mentioned automated systems allows for a qualitative change in the paradigm of digital support for stages of the product life cycle. Digital twins are at the very center of industrial automation, being a concentrator of breakthrough IT technologies in production, which are usually called flexible production systems, and recently, with the development of digital technologies, they have come to be called cyber-physical systems.

By the term production process, we shall mean the process of creation (design and manufacture) and maintenance of a product in working condition based on an artificially created, as a rule, anthropotechnical cyber-physical system [10]. Regardless of the wide variety of definitions of the "life cycle" in modern international and national standards, we note that the production process covers all stages of the product life cycle – from the emergence of the need for the product to the stage of its disposal or recycling (Fig. 3).

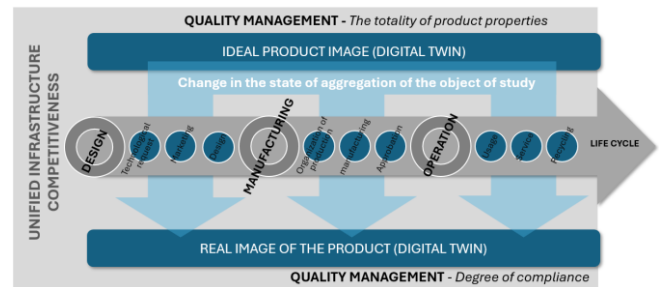


Fig. 3. Infrastructure of quality of digital models of the product

At the design stage, the genesis of the need, the design of general principles, machine architecture, the creation of specific forms and requirements occur. The manufacturing stage is closely related to the preparation of production and the creation of conditions for transformations), manufacturing, and subsequent testing of transformations. Operational processes include the use of the product by end users, service maintenance, including the restoration of lost properties and the disposal of the product, as well as the possible recycling of its parts and materials.

At the early stages of creating a product, its ideal (abstract) image is formed as a set of refined properties, which are the focus of the enterprise's quality management system. In the process of passing through the stages of the product life cycle, a transition to a real image occurs at the manufacturing stage, and then degradation (loss of properties) of the product occurs during its operation. Obviously, the digital twin should ensure these patterns of transformation, affecting both the properties of the product and the scenarios of its behavior and functions at each moment of its "life". A digital twin can be an appropriate solution at all stages of the product life cycle. In this case, when speaking about the creation of a product, it is necessary to separate the object and the subject of the production process. The object will be the manufactured product itself, which is the result of the production process. The subject will be the process of manufacturing the product itself and the production that embodies it (Fig. 4).

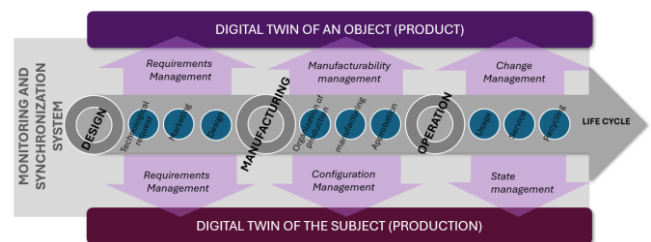


Fig. 4. Synchronization of digital models of the object and the subject of production

The formation of digital twins of the object and the subject of production, as well as their interaction, are extremely complex interrelated and interdependent tasks. At the same time, the interconnected coordinated digital models of the object and the subject of production form the digital contour of the enterprise. To maintain its operability, it is necessary to have a system for monitoring and synchronizing the state of the models, as well as maintaining models of internal integration and external connections with real copies of products and production processes at the enterprise [11,12].

It is important to note the commonality of the principles for constructing a digital twin of a product and a production process, based on the principles of flexibility (such as

maintaining direct and feedback with the object of the production process), dynamism (as the need to apply key concepts of simulation modeling), observability (as the use of advanced capabilities for visual representation of objects and

low-code modeling tools). Table shows the relationship between the main principles and target metrics for developing digital twins of a product and a production process (Table 1).

TABLE I. COMMON PRINCIPLES OF CONSTRUCTING DIGITAL TWINS

Construction principles	Digital twin of a product	Digital twin of production (process)
Flexibility:	Detailed direct and feedback communication with the production process object.	
Dynamics:	The need to use key concepts of simulation modeling.	
Observability:	Advanced object visualization capabilities.	
Purposes of creation:	<ul style="list-style-type: none"> Requirements Management. Manufacturability Management Change Management. 	<ul style="list-style-type: none"> Configuration Management Situational Management (Operational) State Management (Forecasting)
Tasks:	<ul style="list-style-type: none"> Difficulty in forecasting operation under normal and abnormal conditions. Organization of the manufacturing process. Forecast and assessment of the current state. 	<ul style="list-style-type: none"> Complexity of forecasting the production situation. Optimization of material flows Ensuring the operability of equipment
Problems:	<ul style="list-style-type: none"> Complexity of the design model. Complexity of the manufacturing process model Difficulty in obtaining adequate information about the current state of the object 	<ul style="list-style-type: none"> Large number of interconnected models. Complexity of the organizational model. Complexity of the technological environment model.

The main purpose of creating a digital twin of a manufacturing object is to ensure the competitiveness of manufactured products, which is achieved by the subsystems (components) of requirements management, manufacturability management and change management. The main competitive advantages of developing digital twins of products at different stages of the product life cycle are prompt changes to the design before manufacturing, rapid adaptation of the design to the technological environment, and the ability to improve the product design based on application experience. Digital twins of products are aimed at solving problems that arise in almost any production, including the complexity of predicting operation under normal and abnormal conditions, effectively organizing the manufacturing process, predicting and assessing the current state of the product. When introducing digital twins of products, an enterprise expects an increase in the competitiveness of products, including an increase in the quality of the design of products, saving technological resources for production, and reducing operating costs.

The main purpose of creating a digital twin of a manufacturing entity is to optimize the use of various resources of the production technological environment, which is understood as a set of technological equipment united by a common target purpose. The following functional subsystems are aimed at achieving the goal within a given type of digital twin: configuration management, situational management, and state forecasting. The main competitive advantages of developing digital twins of production processes at different stages of the product life cycle are the rational use of various types of resources, rational planning and organization of production, and proactive maintenance of equipment. Digital twins of production are aimed at solving a wide range of problems, including the complexity of forecasting production situations, optimizing material flows, ensuring the operability of equipment, etc. When implementing digital twins of production, an enterprise expects positive returns on production, such as guarantees of

meeting requirements, reducing production losses, and reducing operating costs.

At the same time, common to all these stages of the life cycle is the high complexity of digital models. Given the specifics and scale of production, the implementation of such digital models requires optimization of costs for digital modeling and physical prototyping, as well as an assessment of the share of costs for digital modeling in the cost of finished products.

The level of enterprise digitalization can be measured by assessing the level of the used digital production models, reflecting the extent of their isomorphism to the real object (Fig. 5).

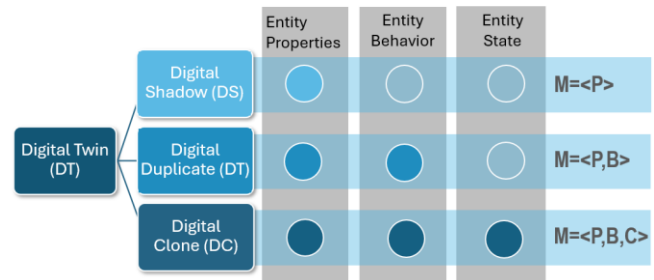


Fig. 5. Functional expansion of digital twin categories

From the point of view of the functional expansion of digital twins, 3 categories can be distinguished: Digital Shadow (DS), Digital Duplicate (DD), Digital Clone (DC). In this case, the capabilities of each selected category extend to the following functional areas: a set of properties of the modeled entity (P), the behavior of the entity (B), the state of the entity at a given point in time (C).

The category "Digital Shadow" is the simplest version of the implementation of a digital twin, primarily based on managing the properties of the modeling object. For example, information systems about an object or production process containing data sets in storage and presenting the results in the form of diagrams, graphs or dashboards. For example, a

typical database management system associated with the modeling object can act as a modeling tool. The resource costs for creating such a model are relatively small.

The "Digital Duplicate" category is a more complex version of a digital model that increases its functionality in the field of modeling object behavior scenarios. For example, models for transporting blanks and providing the production process with material resources, models for the operation of assembly production lines and conveyors, models for the functioning of specific types of equipment, etc. Such a digital twin has a more complex architecture, since it reflects the behavioral capabilities of the modeled object and includes the functionality of dynamic simulation models. The resource costs for creating such a model increase sharply, therefore, they require a thorough feasibility study of the application. The "Digital Clone" category is the most complex version of implementing a digital twin, since it is aimed at monitoring and modeling the dynamics of the object's state depending on the current production or operating conditions. For example, smart service of process equipment during use and loss of specified performance properties, crash test systems for high-tech products, monitoring systems for complex transport devices or high-risk systems, etc. Such models maximally reflect the nature of the modeled object with a high degree of observability. The basis for the formation of this version of a digital twin is the conditions for modeling open systems, monitoring environmental conditions and external influences, identifying random objects and events, interacting with a large number of heterogeneous entities in heteromorphic environments, etc. However, the cost and duration of creating such models can be significant, which will require deep justification and an assessment of the effectiveness of the decisions taken during its creation.

III. CONCLUSION

In conclusion, it should be noted that the creation of digital twins of the product and the production process is a relevant, but methodologically and technically complex solution that requires a detailed feasibility study, while:

1. Automation of production includes two complementary components aimed at mechanization and digitalization of product creation processes. The development of computer technologies and computing capabilities has made it possible to practically implement theoretical mathematical models in the field of IT services.

2. The level of digitalization of an enterprise is an integral marker of its competitiveness system, by which one can assess the prospects for its further development

3. The main software tool for automating and improving the quality of products created for enterprises within the framework of the Industry 4.0 paradigm is the creation of digital twin models.

4. In the process of forming digital models, it is necessary to distinguish between the digital twin of the product (object) and the digital twin of the process of its production (subject). The interrelations of these types of

digital models form a single contour of enterprise digitalization and link the processes of the production life cycle into a single whole.

5. The use of a digital twin can be an effective solution at all stages of the life cycle of a production facility, including design stages, where the ideal image of the product is formed; manufacturing stages, where the physical appearance of the product is created, and operation stages, where the product image is degraded;

6. The general concept of creating a digital twin of a product and production process is based on the general principles of flexibility, dynamism, and observability of subjects and objects of modeling;

7. The digital twin, according to the degree of isomorphism to the production facility (subject), increases its functional characteristics in three categories: "Digital Shadow" (DS), "Digital Duplicate" (DD), "Digital Clone" (DC). This division allows us to evaluate the functional capabilities of the model and the degree of its compliance with the real production facility (subject) of modeling, as well as the costs of resources required to create such a model.

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Privacy-Preserving Intrusion Detection in Corporate Networks via Federated and Differentially Private Deep Learning

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Abstract— This paper presents a privacy-preserving approach to intrusion and privacy-violation detection in corporate networks, leveraging federated learning and differentially private deep neural networks. The proposed system enables collaborative model training across distributed organizational units without sharing raw data, ensuring compliance with modern privacy regulations. Experiments on benchmark datasets demonstrate that the method achieves high detection accuracy while maintaining strong formal privacy guarantees. For example, FL + DP-DNN achieved 95.1% accuracy and $\epsilon = 1.85$ on the CICIDS 2018 dataset, demonstrating a strong privacy-utility trade-off. The results confirm the feasibility of deploying advanced analytics for network security without compromising individual or organizational privacy.

Keywords— Privacy-preserving machine learning, federated learning, differential privacy, intrusion detection, corporate networks, insider threat, compliance

I. INTRODUCTION

The increasing digitalization of corporate environments has led to a dramatic rise in both the volume and complexity of cyber threats. Modern organizations face not only external attacks but also insider threats, where legitimate users may intentionally or inadvertently compromise sensitive information. At the same time, the enforcement of stringent privacy regulations such as the General Data Protection Regulation (GDPR) and the California Consumer Privacy Act (CCPA) has made it imperative for organizations to protect personal and organizational data during all stages of security analytics [1],[2].

Traditional intrusion detection systems (IDS) and privacy-violation detection mechanisms often require centralized aggregation of raw network and user data, which can expose organizations to privacy risks and regulatory non-compliance. Recent advances in machine learning, particularly federated learning and differential privacy, offer promising solutions by enabling collaborative model training without sharing sensitive data.

This paper proposes a novel, privacy-preserving framework for intrusion and privacy-violation detection in corporate networks. The approach combines federated learning, which allows distributed organizational units to collaboratively train models without exchanging raw data, and differentially private deep neural networks, which provide formal privacy guarantees for individuals and organizations.

The main contributions of this work are as follows:

- A modular, end-to-end methodology for privacy-preserving intrusion and privacy-violation detection, adaptable to centralized, federated, and edge environments.

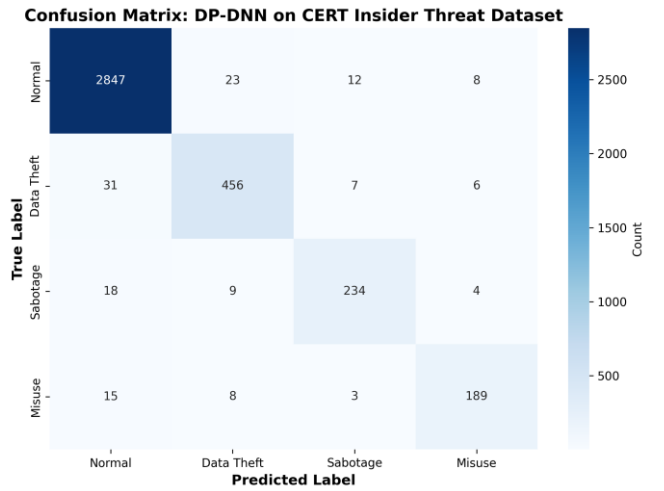


Fig. 1. System architecture showing data flow from distributed clients through federated learning to privacy-preserving inference.

- Integration of context-aware feature engineering, federated learning, and differentially private deep learning for robust and compliant security analytics.
- Comprehensive experimental validation on real-world datasets, showing that the proposed approach achieves state-of-the-art detection performance with minimal utility loss and strong privacy guarantees.

II. RELATED WORK

The intersection of machine learning and network security has produced significant advances in intrusion and privacy-violation detection. Traditional machine learning approaches, such as random forests and support vector machines, have demonstrated strong performance on benchmark intrusion detection datasets [3]. However, these methods typically require centralized data aggregation, raising concerns about privacy and regulatory compliance.

To address these challenges, federated learning (FL) has emerged as a promising paradigm for distributed model training without sharing raw data. FL has been successfully applied to network intrusion detection, enabling collaborative analytics across multiple organizational units while preserving data locality [1],[3],[4]. Recent studies have shown that FL-based systems can achieve detection performance comparable to centralized approaches, with the added benefit of enhanced privacy.

Differential privacy (DP) provides formal guarantees that individual data points cannot be inferred from model outputs, even by adversaries with auxiliary information. The integration of DP with deep learning, particularly through differentially private stochastic gradient descent (DP-SGD), has enabled the development of privacy-preserving models for sensitive domains, including healthcare and finance. In the context of network security, DP has been used to protect user and organizational privacy during both training and inference, with minimal impact on detection accuracy [5], [6].

Recent surveys highlight the growing adoption of privacy-preserving machine learning techniques in cybersecurity, emphasizing the need for robust, scalable, and explainable solutions [1], [3], [8]. However, challenges remain in balancing privacy, utility, and computational efficiency, especially in large-scale, real-world deployments.

III. PROBLEM STATEMENT AND METHODOLOGY

A. Problem Statement

Corporate networks are increasingly targeted by sophisticated cyber threats, including both external attacks and insider violations. Traditional intrusion detection systems (IDS) often require centralized collection and analysis of sensitive network and user data, which can conflict with privacy regulations such as GDPR and CCPA. This creates a critical need for detection systems that can identify malicious activity while preserving the privacy of individuals and organizations [2], [4].

B. Proposed Methodology

To address these challenges, we propose a modular, privacy-preserving detection framework that integrates federated learning (FL) and differentially private deep neural networks (DP-DNN). The key components of the methodology are as follows:

1) Context-Aware Feature Engineering

Network flow records and user activity logs are preprocessed to extract both technical and contextual features. Feature selection is performed using recursive elimination and correlation analysis.

2) Federated Learning for Distributed Training

The corporate network is partitioned into multiple clients (e.g., organizational branches or departments). Each client trains a local model on its own data, and only model updates (not raw data) are shared with a central server. Secure aggregation protocols ensure that individual updates remain confidential.

3) Differentially Private Deep Learning

To provide formal privacy guarantees, differentially private stochastic gradient descent (DP-SGD) is applied during model training. Gaussian noise is added to gradient updates, and a privacy accountant tracks the cumulative privacy loss (ϵ). The privacy budget is set to $\epsilon \leq 2$, balancing privacy and utility [5], [6].

A randomized algorithm M satisfies (ϵ, δ) -differential privacy if for all datasets D and D' differing by at most one record, and for all possible outputs S :

$$\Pr[M(D) \in S] \leq e^{\epsilon} \cdot \Pr[M(D') \in S] + \delta \quad (1)$$

The DP-SGD algorithm adds Gaussian noise to gradients:

$$\tilde{g}_t = (1/L) \sum \text{clip}(\nabla_{\theta} \ell(x_i, y_i; \theta_{t-1}), C) + N(0, \sigma^2 C^2 I) \quad (2)$$

The global model parameters are updated using federated averaging:

$$\theta_{t+1} = \sum (n_k/n) \theta_k(t) \quad (3)$$

The cumulative privacy loss is tracked using the moments accountant:

$$\epsilon = \min_{\alpha > 1} \{ [\log M_{\alpha}(q, \sigma, T)] / (\alpha - 1) \} \quad (4)$$

C. Model Evaluation and Deployment

The trained models are evaluated on benchmark datasets using accuracy, macro-F1, and ROC-AUC as primary metrics. Inference latency and resource utilization are measured to ensure suitability for real-time deployment.

TABLE I. DETECTION PERFORMANCE COMPARISON

Model	Dataset	Accuracy	Macro-F1	Privacy Budget (ϵ)
Random Forest	CICIDS 2018	0.972	0.963	—
XGBoost	CICIDS 2018	0.975	0.965	—
DNN	CICIDS 2018	0.981	0.974	—
DP-DNN	CICIDS 2018	0.963	0.951	1.98
FL + DP-DNN	CICIDS 2018	0.951	0.938	1.85
DNN	CERT v6.2	0.953	0.941	—
DP-DNN	CERT v6.2	0.938	0.921	1.95
FL + DP-DNN	CERT v6.2	0.927	0.911	1.82

IV. EXPERIMENTS

A. Datasets

In this section, we describe the datasets used in our experiments, and the two datasets are CICIDS 2018 and CERT Insider Threat v6.2. CICIDS 2018 is a network traffic dataset that includes both normal and malicious activities, and CERT Insider Threat v6.2 is a dataset that simulates insider threat scenarios in a corporate environment.

B. Experiment Setup

We performed our experiments in a federated learning setting, and the datasets were distributed among multiple clients to create a distributed data scenario. Each client had its own data subset, and no raw data was exchanged between clients or with the central server, therefore federated learning was performed using the Federated Averaging (FedAvg) algorithm. We introduced Gaussian noise into the gradient updates to preserve privacy, adopting the differentially private SGD (DP-SGD) method, thus ensuring the privacy of the data.

C. Performance Metrics

We assessed the effectiveness of our framework using various metrics, and these metrics include accuracy, macro-F1 score, ROC-AUC, inference latency, privacy budget (ϵ), and resource usage. Accuracy refers to the percentage of correctly classified examples, and macro-F1 score is a balanced measure of precision and recall (Fig. 2). ROC-AUC measures the model's ability to distinguish between classes, and inference latency is the time it takes for the model to make predictions, so it is an important metric for real-time applications. Privacy budget (ϵ) is a measure of the privacy guarantee provided by the differentially private model, and resource utilization refers to the computational resources required for training and inference, which is crucial for deploying the model on edge devices.

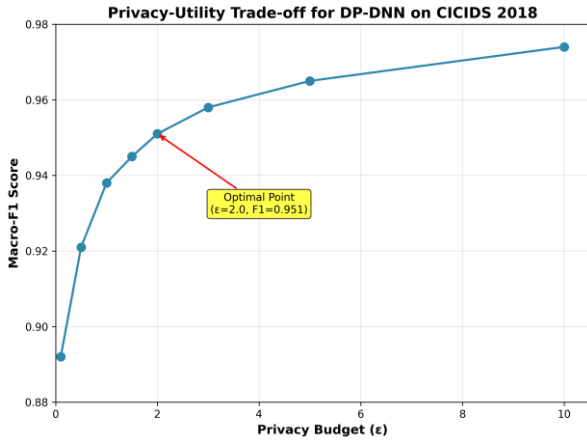


Fig. 2. Privacy-utility trade-off: Macro-F1 score vs. privacy budget (ϵ) for DP-DNN on CICIDS 2018 dataset.

V. RESULTS

The results show that the proposed differentially private and federated models achieve high detection accuracy and macro-F1 scores, with only a minor reduction in performance compared to non-private baselines. Table II shows the resource utilization and scalability of the proposed privacy-preserving models. Compared to similar FL-IDS frameworks [2], [4], our approach maintains competitive accuracy while achieving stronger formal privacy bounds ($\epsilon \leq 2$). The privacy-utility trade-off analysis demonstrates that detection performance remains high even with strong privacy guarantees. The federated learning system scales effectively with up to 100 clients, and resource utilization measurements confirm real-time inference capabilities.

TABLE II. RESOURCE UTILIZATION AND SCALABILITY

Model	Training Time (min)	Memory Usage (GB)	Inference Latency (ms)	Model Size (MB)
Random Forest	12.3	2.1	4.2	45.2
XGBoost	18.7	3.4	5.1	52.8
DNN	45.2	8.9	8.3	124.5
DP-DNN	67.8	12.3	9.1	124.5
FL + DP-DNN	89.4	15.7	11.2	124.5

The privacy-utility trade-off analysis (Fig.2) demonstrates that detection performance remains high even with strong privacy guarantees. The federated learning system scales effectively with up to 100 clients (Fig. 3), and resource utilization measurements confirm real-time inference capabilities.

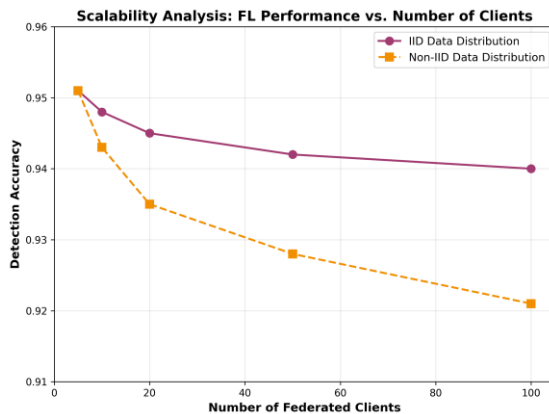


Fig. 3. Scalability analysis: Detection accuracy vs. number of federated clients with different data distributions.

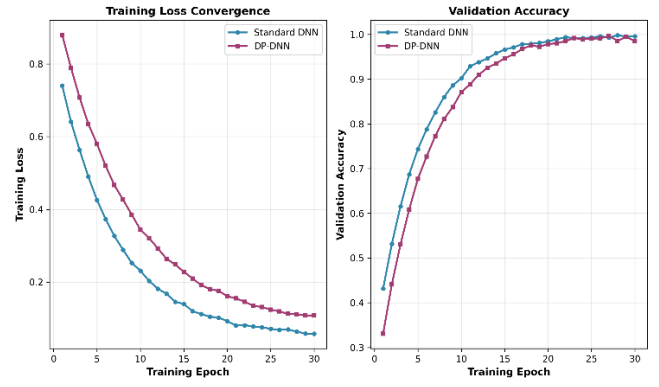


Fig. 4. Confusion matrix for DP-DNN model on CERT insider threat detection dataset.

VI. CONCLUSION

This paper has presented a privacy-preserving framework for intrusion and privacy-violation detection in corporate networks, integrating federated learning and differentially private deep neural networks. Experimental results on benchmark datasets demonstrate that the approach achieves high detection accuracy and macro-F1 scores, with only a minor reduction in performance compared to non-private baselines. The system maintains strong formal privacy guarantees ($\epsilon \leq 2$) and meets real-time inference requirements, making it suitable for practical deployment in diverse organizational settings. While the proposed framework demonstrates strong performance, it does incur higher training time and memory usage due to privacy constraints. Future optimizations could explore lightweight architecture and communication-efficient aggregation. Future work will focus on extending the framework to address emerging threats, improving model explainability, and evaluating long-term performance in real-world deployments.

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Method for Determining the Sign in the Residue Number System Based on the Chinese Theorem on Fractional Remainders

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Abstract— Determining the sign of a number is one of the key problems solved in the residue number system. This operation is important because it serves as a basis for implementing more complex calculations, such as comparing numbers and division. Traditional approaches use specially selected sets of modules, which limits their application to certain cases. In this paper, a new algorithm for determining the sign of a number in the residue number system is proposed, based on the application of the Chinese theorem on fractional remainders. The developed method ensures the execution of the operation without the need to select special modules, which makes it more universal. The results of software modeling showed that the proposed algorithm has higher performance compared to the existing method using fast transformation in the generalized positional number system. This allows applying the proposed solution in various types of residue number system, including digital signal processing problems.

Keywords—residue number system, non-modular operations, determining the sign of a number, set of modules, fractional values, dynamic range.

I. INTRODUCTION

The residue number system (RNS) is an effective tool for accelerating arithmetic operations by parallel processing of numbers with a small bit depth. This allows to significantly reduce the execution time of such basic operations as addition, subtraction, and multiplication. Due to these advantages, RNS is widely used in problems related to modular arithmetic, especially in the field of digital signal processing [1], [2] and cryptography [3]. Currently, active developments are underway on high-performance and reliable RNS-based solutions used in such areas as cloud computing [4], wireless sensor networks [5], satellite communications [6], and bioinformatics, including calculations using DNA [7]. However, despite the obvious advantages, RNS also has a number of limitations. One of the main challenges is the implementation of non-modular operations, such as determining the sign of a number, comparison, overflow detection, division, root extraction, and others. Since these operations do not fit into the framework of modular arithmetic, the search for efficient algorithms for their implementation remains a pressing scientific problem. In recent years, many studies have appeared aimed at optimizing these operations for specific modular sets, for example, of the type $2^n \pm 1$, $2n \pm 1$. The modern

development of the RNS theory is characterized by many specialized solutions, each of which is focused on a specific set of modules, often having no intersections with others. As a result, a modular set suitable for one problem may not be applicable to another [8], which significantly complicates the practical implementation of RNS due to fragmentation and the lack of universal solutions.

Some works, in particular [9], attempted to systematize existing approaches related to addition and multiplication operations in various RNS configurations. However, issues related to other operations, including determining the sign, remain open and require further study.

Determining the sign of a number in RNS is one of the fundamental problems, since algorithms for more complex operations, such as comparison and division, are built on its basis. Although efficient sign determination algorithms currently exist, they are typically designed for strictly defined sets of moduli. For example, [10] considers a set of moduli for an RNS of the form $\{2^{n+1} - 1, 2^n - 1, 2^n\}$, and [11] an approach for the set $\{2^n - 1, 2^n, 2^n + 1\}$. [12] analyzes these moduli in relation to methods for obtaining numbers in a system with a mixed base. [13] proposes an algorithm that requires generating moduli according to certain conditions. The authors of [14] developed a method for comparing numbers for a set of five moduli, including $\{2^n - 1, 2^n, 2^n + 1, 2^{n+1} - 1, 2^{n-1} - 1\}$. Their method involves scaling the operands and their difference by a factor of $(2^{2n} - 1)(2^{n-1} - 1)$, which allows for a significant reduction in the bit depth of adders — from $5n$ bits to n and $n + 1$ bits.

This paper proposes a new universal approach to solving the problem of determining the sign of a number in RNS. The developed algorithm is not limited to specific sets of modules, which ensures its wide applicability in various variants of the residual class system.

II. BACKGROUND ON RESIDUE NUMBER SYSTEM

The residue number system (RNS) is defined by a set of pairwise mutually prime positive numbers $\{m_1, m_2, \dots, m_n\}$, called modules. The product of all modules $M = m_1 m_2 \dots m_n$ defines the full range of representation of numbers in this system. Any integer X , located in the range

from $0 \leq X < M$, can be uniquely represented in the SRC as residues $(x_1, x_2, \dots, x_n)$, where each element x_i is equal to the remainder of dividing X by the corresponding module m_i .

$$x_i = X \bmod m_i = |X|_{m_i}, 0 \leq x_i < m_i. \quad (1)$$

To be able to represent both positive and negative numbers in the residual class system, the full range of M values is conventionally divided into two approximately equal parts: one for positive numbers, the other for negative numbers. In this approach, the sign of the number X is determined by which of these parts it is in. In particular:

$$\text{for odd } M: -\frac{M-1}{2} \leq X \leq \frac{M-1}{2} \quad (2)$$

$$\text{for even } M: -\frac{M}{2} \leq X \leq \frac{M}{2}$$

Within these limits, the value of X can be uniquely represented in the residual class system.

In the residual class system, the arithmetic operations of addition, subtraction, and multiplication are performed according to the following rules:

addition and subtraction:

$$X \pm Y = (|x_1 \pm y_1|_{m_1}, |x_2 \pm y_2|_{m_2}, \dots, |x_n \pm y_n|_{m_n}) \quad (3)$$

multiplication:

$$X \cdot Y = (|x_1 \cdot y_1|_{m_1}, |x_2 \cdot y_2|_{m_2}, \dots, |x_n \cdot y_n|_{m_n}) \quad (4)$$

These expressions illustrate one of the key advantages of RNS: all calculations are performed independently and in parallel for each module, which contributes to high processing speed.

In fault-tolerant systems, a redundant residual class system (RRNS) is used, in which modules are divided into two types information and redundant. Inclusion of additional (redundant) modules expands the overall range of the system compared to the range specified only by information modules. Residuals obtained for redundant modules allow for efficient detection and correction of errors. One of the current problems within the framework of RNS theory remains the construction of efficient algorithms for determining the sign of a number represented as a vector of residuals $(x_1, x_2, \dots, x_n)$. In the future, a new method will be proposed that allows one to determine whether a given number belongs to the domain of positive or negative values in RNS.

III. ALGORITHM FOR DETERMINING THE SIGN OF A NUMBER IN RESIDUE NUMBER SYSTEM

The theoretical basis for calculating the positional value of a number in a residue number system (RNS) is to transform the number into positional form using the Chinese Remainder Theorem (CRT). If in an RNS with modules $m_1, m_2, \dots, m_n$ a number X satisfying the condition $0 \leq X < M = m_1 m_2 \dots m_n$ is represented as a set of residues $X = (x_1, x_2, \dots, x_n)$, then the original number X is restored from these residues using the following formula:

$$X = \left| \sum_{i=1}^n x_i |M_i^{-1}|_{m_i} M_i \right|_M, \quad (5)$$

where $M_i = \frac{M}{m_i}$, a $|M_i^{-1}|_{m_i}$ denotes the multiplicative inverse of the number M_i^{-1} modulo m_i .

If we divide (5) by M , we get:

$$\frac{X}{M} = \left| \sum_{i=1}^n x_i \frac{|M_i^{-1}|_{m_i} M_i}{M} \right|_1, \quad (6)$$

where $| \cdot |_1$ the entry denotes the fractional part of the

number. We introduce the notation $k_i = \frac{|M_i^{-1}|_{m_i} M_i}{M}$, then we rewrite (6):

$$\frac{X}{M} = \left| \sum_{i=1}^n x_i k_i \right|_1. \quad (7)$$

The values $\frac{X}{M}, k_1, k_2, \dots, k_n$ are fractional numbers (infinite periodic fractions) lying in the interval $[0, 1)$. In this case, the coefficients k_i depend exclusively on the selected modules of the ROC and, therefore, are its constant characteristics.

Comparison of formulas (5) and (7) allows us to highlight a number of practical differences. Formula (5) requires the operation of taking the remainder by a large modulus M , which is associated with high computational complexity. In turn, in formula (7), the operation of taking the remainder is replaced by calculating the fractional part of the number, which significantly simplifies the implementation; in fact, it comes down to removing the integer part, that is, to transferring to the units place. However, this advantage is accompanied by a significant disadvantage: calculations using formula (7) require working with infinite fractions. In this regard, an important question arises: with what accuracy should calculations be performed using formula (7) so that the positional value of the number X is restored correctly.

Let $F\left(\frac{X}{M}\right)$ denote an infinite binary fraction corresponding to the value $\frac{X}{M}$. By discarding all bits in this fraction starting from the $(N+1)$ -th after the decimal point, we obtain a finite binary fraction $\left[F\left(\frac{X}{M}\right)\right]_{2^{-N}}$. For example, if $F\left(\frac{X}{M}\right) = 0,010101010\dots$ then $\left[F\left(\frac{X}{M}\right)\right]_{2^{-5}} = 0,01010$. In this case, the following relation is satisfied: $\left[F\left(\frac{X}{M}\right)\right]_{2^{-N}} < F\left(\frac{X}{M}\right) < \left[F\left(\frac{X}{M}\right)\right]_{2^{-N}} + 2^{-N}$, describing the position of the exact value of $F\left(\frac{X}{M}\right)$ relative to the rounded value $\left[F\left(\frac{X}{M}\right)\right]_{2^{-N}}$. The use of fractional values in the residue number system has proven to be very effective in performing division operations [15]. This paper will demonstrate how these values can be used to determine the sign of a number in the RNS.

Let us assume that rounded constants $\left[F(k_i)\right]_{2^{-N}}$ are used for calculations according to formula (7). Then the question of the correctness of using such rounded values when inverting a number from the RNS to a positional number system is solved using the following theorem.

Theorem 1. The smallest value of N for which the restoration of the positional value of the number X by the formula

$$\frac{X}{M} = \left| \sum_{i=1}^n x_i \left[F(k_i)\right]_{2^{-N}} \right|_1 \quad (8)$$

will be correct, equal

$$N = \lceil \log_2(M\mu) \rceil, \quad (9)$$

where $\mu = -n + \sum_{i=1}^n m_i$

Using formula (8) with the calculation accuracy N , defined by formula (9) to perform the inverse transformation

of a number X is approximately equivalent in complexity to performing the same transformation using formula (5). A natural question arises: is it possible to reduce the calculation accuracy (the value of N) in formula (8). It turns out that such a reduction is possible to perform the operation of determining the sign of a number in RNS.

When determining the sign of a number in RNS, there is no need to restore its exact location on the number axis, as is required by formulas (5) or (7). To correctly determine the sign, it is enough to simply know which of the intervals the number under study falls into. If in formula (8) we use a reduced value of $\tilde{N}$ instead of N , $\tilde{N} < N$ at which the interval will increase. As a result, several fractions corresponding to different numbers in RNS may fall into this interval, which makes the use of $\tilde{N}$ for the inverse transformation incorrect. However, when solving the problem of determining the sign of a number in RNS, this increased interval can still be used. An arbitrary interval $[\sum_{i=1}^n [F(k_i)]_{2^{-\tilde{N}}x_i}, \sum_{i=1}^n [F(k_i)]_{2^{-\tilde{N}}x_i} + 2^{-\tilde{N}} \sum_{i=1}^n x_i]$ can contain no more than $2^{-\tilde{N}} M \sum_{i=1}^n x_i$ fractions $F(\frac{x}{M})$ corresponding to different numbers in the RNS. If we take into account that $0 \leq x_i < m_i$ (according to formula (1)), then:

$$\max\{2^{-\tilde{N}} M \sum_{i=1}^n x_i\} = 2^{-\tilde{N}} M(-n + \sum_{i=1}^n m_i) = 2^{-\tilde{N}} M\mu.$$

To determine the sign of a number in the RNS by its fractional value $F(\frac{x}{M})$, it is necessary to check the following relationships:

$$\text{If } 0 < F(\frac{x}{M}) < \frac{1}{2}, \text{ then } X \text{ is positive} \quad (10)$$

$$\text{If } \frac{1}{2} < F(\frac{x}{M}) < 1, \text{ then } X \text{ is negative.}$$

Τη προποσεδ αλγοριτημ ισ βασεδ ον τη υσε οφ τη π αλυε $[F(\frac{x}{M})]_{2^{-N}}$ φορ τη ρεφινινγ ιτερατιον, ωηερε τηε πααλυε οφ N ισ χαλχυλατεδ υσινγ φορμυλα (9).

Proposed Algorithm for determining the sign of a number in RNS

Input data:

- 1: $\{m_1, m_2, \dots, m_n\}$
- 2: $M = m_1 m_2 \dots m_n$,
- 3: $\mu = -n + \sum_{i=1}^n m_i$
- 4: $N = \lceil \log_2(M\mu) \rceil$
- 5: $k_i = \frac{|M_i^{-1}|_{m_i} M_i}{M}$
- 6: $[F(k_i)]_{2^{-N}}$
- 7: $[F(\frac{x}{M})]_{2^{-N}} = [\sum_{i=1}^n x_i [F(k_i)]_{2^{-N}}]_1$
- 8: If $0 < [F(\frac{x}{M})]_{2^{-N}} < \frac{1}{2}$, then $X > 0$
- 9: If $\frac{1}{2} < [F(\frac{x}{M})]_{2^{-N}} < 1$, then $X < 0$

Output data:

- 10: X

As shown in Theorem 1, the accuracy N of the given algorithm is sufficient for the correct determination of the sign of a number in RNS. The use of such accuracy is

approximately equivalent in complexity to the implementation of the transformation by CRT.

IV. RESULTS AND DISCUSSION

To evaluate the efficiency of algorithms for determining the sign of a number, a comparative analysis of two approaches was performed: the fast transformation method in the generalized positional numeral system described in [16] and the proposed method based on the Chinese Remainder Theorem (CRT) with fractional values. The simulation was performed using the Python programming language version 3.11. All calculations were performed on a personal computer with an Intel Core i5-12450H processor, 16 GB of RAM and a 64-bit Windows 10 operating system.

To test the proposed algorithm, six variants of the residue number system were selected, presented in Table 1. The choice of these modular sets is due to their ability to cover numerical ranges from 2^{96} to 2^{224} bits.

The execution time, measured in seconds, was used as the main comparison criterion. For each set of modules, 10000 iterations were performed by both algorithms. Table 2 show the average execution times obtained during the simulation.

TABLE I. SETS OF RNS MODULES COVERING DIFFERENT DYNAMIC RANGES

Dynamic range	n	Set of modules
RNS_1 $M > 2^{96}$	7	13429, 13439, 13441, 13447, 13449, 13450, 13451
RNS_2 $M > 2^{128}$	5	50859005, 50859007, 50859011, 50859012, 50859013
RNS_3 $M > 2^{168}$	6	268435451, 268435453, 268435457, 268435459, 268435460, 268435461
RNS_4 $M > 2^{192}$	7	180643657, 180643663, 180643667, 180643669, 180643671, 180643672, 180643673
RNS_5 $M > 2^{224}$	8	268435441, 268435451, 268435457, 268435459, 268435461, 268435463, 268435465, 268435466

The proposed algorithm demonstrates a speed advantage in all tested variants. Thus, for the set of modules RNS_1 , the execution time is reduced by approximately 1.6 times compared to the algorithms based on the mixed radial coordinates (MRC) method. In the case of RNS_2 the speedup is about 1.3 times, for RNS_3 about 1.5 times, and a similar speedup is observed for RNS_4 . For the fifth set of modules, the reduction in time was 1.6 times.

In other words, the execution time of the proposed method is only 63–79% of the execution time of the algorithm described in [16]. Specific values depend on the characteristics of the selected RNS, including modules, their number and structure.

TABLE II. THE RUNNING TIME OF ALGORITHMS FOR DETERMINING THE SIGN OF A NUMBER IN RNS

RNS	Proposed algorithm (c)	MRC method (c)
RNS_1	0.4335	0.6884
RNS_2	0.5527	0.6964
RNS_3	0.5637	0.8348
RNS_4	0.6585	1.0028
RNS_5	0.8319	1.3017

The obtained results allow us to state that the proposed algorithm for determining the sign of a number in a system of residual classes demonstrates higher performance compared to the existing analogue used for RNS with general modules.

V. CONCLUSIONS

The algorithm for determining the sign of a number in a residue number system developed in this paper is based on the use of fractional values. Since in most cases there is no need to accurately restore the numerical value when determining the sign, one iteration of a rough estimate is sufficient. Correctly selected calculation accuracy allows us to reduce the number of processed digits to a value proportional to the logarithm of the RNS range, while the best known methods have a linear dependence on the range.

The simulation results showed that the proposed algorithm outperforms the algorithm based on the mixed radial coordinates (MRC) method in speed, and this advantage is preserved for arbitrary sets of modules. For specialized RNS with modules of the form $2^n \pm 1$, $2n \pm 1$, etc., faster, highly specialized algorithms can be implemented; however, unlike them, the proposed approach is universal and does not depend on the structure of the modular set. This makes it especially relevant for systems with dynamically changing parameters. The proposed algorithm allows to significantly speed up the execution of the sign determination operation, which is the basis of other computationally complex tasks in RNS, such as number comparison, division, overflow control, error localization, etc. Increasing the efficiency of basic operations opens up opportunities for expanding the practical application of the residual class system, especially in digital signal processing, cryptography, and other resource-intensive computing areas.

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Automatic Camera Calibration Method for Solving the Problem of Moving Object Detection

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Abstract— Camera calibration is a key task in computer vision and plays an important role in many applications related to visual surveillance. A calibrated camera allows correcting perspective distortions of an object's image. In addition, it provides the ability to extract metric information from images that is robust to changes in viewing angle. Using calibrated cameras, it is possible to use pre-known 3D models to estimate the spatial position of objects, which increases the resilience of detection and tracking systems to noise and partial occlusions. This paper presents an automated method for restoring camera parameters from traffic video recordings. With only camera installation height data, the proposed algorithm allows fully determining both internal and external camera parameters based on the appearance and dynamics of objects in the video. The method has been tested under various conditions, and the results obtained confirm its effectiveness and practical applicability in moving object detection tasks.

Keywords— camera calibration, camera internal parameters, camera external parameters, motion detection, rotation matrix.

I. INTRODUCTION

Camera calibration is one of the important tasks in modern computer vision applications. The relevance of camera calibration is determined by its importance in ensuring the accuracy and reliability of systems using visual data [1]. With the development of technologies, calibration is becoming increasingly necessary for a wide range of applications - from autonomous systems and monitoring [2] to medicine and virtual reality [3]. Accurate and reliable camera calibration methods play a vital role in improving modern technologies, ensuring their efficiency and safety. First, camera calibration helps to compensate for perspective distortions [4] that occur when displaying objects in a two-dimensional image - a task that is significantly difficult for most methods based on 2D image features. Second, calibrated cameras allow you to obtain discriminative metrics that are robust to changes in the scene and viewing angle, which is especially important for tasks such as classification and multi-camera tracking [5]. Thirdly, the presence of a calibrated camera allows using pre-known 3D models to estimate the real position of objects in space, which makes the detection and tracking processes more reliable in the presence of noise or partial occlusions [6]. There are various approaches to camera calibration, so the authors of [5] propose a method for calibrating the external parameters of the camera, which consists of performing two stages of extracting reference point data and optimally transforming

sets of these points. In [6], a new method for camera calibration is described, based on a multi-level analytical model in the form of an ellipse. The algorithm developed in [7] allows obtaining the corresponding points in the world coordinate system and on the image for calibration algorithms with partial capture of calibration panels. However, automatic calibration methods are a more effective way to restore camera parameters in video surveillance problems. Researchers [8] propose a new method for determining the rotation matrix, which translates vectors into the coordinate system of the scene camera. The novelty of the authors of [9] is the automatic calibration technique based on the NetCalib deep neural network. In [10], a new scalable, fully distributed method for simultaneous localization and extrinsic calibration based on Gaussian probability propagation is developed. A fast autocalibration method that efficiently transforms point clouds and extracts spatiotemporal features from point sequences using the deep neural network MRINet is presented in [11].

This paper presents a new method for automatic calibration of a road-tracking camera. The intrinsic and extrinsic parameters of the camera are reconstructed based on the value of the camera height distance. This approach simplifies the process of camera calibration in video surveillance systems. Experimental modeling has shown the effectiveness of the developed camera calibration method.

II. CAMERA CALIBRATION

Camera calibration is the process of determining the parameters of the camera that describe its internal and external geometry. These parameters include both the characteristics of the camera itself and its location and orientation in space relative to the observed scene. This data is of key importance in computer vision tasks.

Let us have a point with coordinates X_c, Y_c, Z_c in the camera coordinate system. Let us project it onto the image plane.

During the formation of the image on the matrix plane, the optical center O_c will determine the point (u, v) at which the projection lines from the lens intersect and at the same time create an accurate representation of three-dimensional objects on a two-dimensional surface. This means the equivalence of points on the image plane and in the 3D coordinates of the camera. Then we get:

$$u = f \frac{X_c}{Z_c}, v = f \frac{Y_c}{Z_c} \quad (1)$$

where f is the focal length.

Let's rewrite it in matrix form:

$$\begin{bmatrix} u \\ v \\ 1 \end{bmatrix} = \frac{1}{Z_c} \begin{bmatrix} f & 0 & 0 \\ 0 & f & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} X_c \\ Y_c \\ Z_c \end{bmatrix} \quad (2)$$

where the 3×3 matrix represents the internal parameters of the camera (K). In the conditions of camera skew γ between the x and y axes, and also in the presence of two different focal lengths, we rewrite the matrix K as:

$$K = \begin{bmatrix} f_x & \gamma & c_x \\ 0 & f_y & c_y \\ 0 & 0 & 1 \end{bmatrix} \quad (3)$$

Then according to (3), we rewrite expression (2):

$$\begin{bmatrix} u \\ v \\ 1 \end{bmatrix} \sim \begin{bmatrix} f_x & \gamma & c_x \\ 0 & f_y & c_y \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} X_c \\ Y_c \\ Z_c \end{bmatrix} \quad (4)$$

In general, the relationship between a 3D point and a point on a 2D plane is represented as:

$$\lambda \tilde{p} = K[R|t]\tilde{P}_w \quad (5)$$

where λ is the scale factor, R and t are the external parameters of the camera for the transition from P_w to P_c , $\tilde{p}$ is a 2D point in homogeneous coordinates, $\tilde{P}_w$ is a 3D point in homogeneous coordinates, K are the internal parameters of the camera.

Then the camera is represented as follows:

$$K = \begin{bmatrix} f_u & \gamma & c_u \\ 0 & f_v & c_v \\ 0 & 0 & 1 \end{bmatrix} \quad (6)$$

For each image there is a 3D-2D relation of pairs of points, and a system of equations of the following form is composed:

$$\lambda \begin{bmatrix} u \\ v \\ 1 \end{bmatrix} = K \begin{bmatrix} r_{11} & r_{12} & r_{13} & t_1 \\ r_{21} & r_{22} & r_{23} & t_2 \\ r_{31} & r_{32} & r_{33} & t_3 \end{bmatrix} \begin{bmatrix} X_w \\ Y_w \\ Z_w \\ 1 \end{bmatrix} \quad (7)$$

$$\lambda \begin{bmatrix} u \\ v \\ 1 \end{bmatrix} = K \begin{bmatrix} r_{11} & r_{12} & t_1 \\ r_{21} & r_{22} & t_2 \\ r_{31} & r_{32} & t_3 \end{bmatrix} \begin{bmatrix} X_w \\ Y_w \\ Z_w \\ 1 \end{bmatrix} \quad (8)$$

Let us introduce the concept of homography. With it, the equation takes the following form:

$$\lambda \begin{bmatrix} u \\ v \\ 1 \end{bmatrix} = \begin{bmatrix} g_{11} & g_{12} & g_{13} \\ g_{21} & g_{22} & g_{23} \\ g_{31} & g_{32} & g_{33} \end{bmatrix} \begin{bmatrix} X_w \\ Y_w \\ 1 \end{bmatrix}$$

or

$$\lambda \begin{bmatrix} u \\ v \\ 1 \end{bmatrix} = G \begin{bmatrix} X_w \\ Y_w \\ 1 \end{bmatrix}$$

where G is a homography that describes the relationship between two projective transformations.

We represent the matrix G as three vectors g_i^T where g_i^T is the i -th row, $[X_w, Y_w, 1]^T$ is represented as $\tilde{P}_w$:

$$\lambda \begin{bmatrix} u \\ v \\ 1 \end{bmatrix} = G \begin{bmatrix} g_1^T \\ g_2^T \\ g_3^T \end{bmatrix} \begin{bmatrix} X_w \\ Y_w \\ 1 \end{bmatrix} \quad (9)$$

$$\lambda \begin{bmatrix} u \\ v \\ 1 \end{bmatrix} = \begin{bmatrix} g_1^T \\ g_2^T \\ g_3^T \end{bmatrix} \tilde{P}_w \quad (10)$$

Inverse transformation of homogeneous coordinates to pixel coordinates:

$$u = \frac{\lambda u}{\lambda} = \frac{g_1^T \tilde{P}_w}{g_3^T \tilde{P}_w} \quad (11)$$

$$v = \frac{\lambda v}{\lambda} = \frac{g_2^T \tilde{P}_w}{g_3^T \tilde{P}_w}$$

Transforms as:

$$P_i^T \cdot g_1 + 0 \cdot g_2^T - u_i P_i^T \cdot g_3^T = 0 \quad (12)$$

$$0 \cdot g_1^T + P_i^T \cdot g_2^T - v_i P_i^T \cdot g_3^T = 0$$

$$\begin{bmatrix} P_i^T & 0^T & -u_i P_i^T \\ 0^T & P_i^T & -v_i P_i^T \end{bmatrix} \begin{bmatrix} g_1 \\ g_2 \\ g_3 \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \end{bmatrix} \quad (13)$$

Let us choose one arbitrary point (u, v) from the image plane, which we will take as the origin of the world coordinate system, so that:

$$\lambda \begin{bmatrix} u \\ v \\ 1 \end{bmatrix} = K[R \quad T] \begin{bmatrix} 0 \\ 0 \\ 0 \\ 1 \end{bmatrix} = KT \quad (14)$$

Since the static camera located inside the car is always at a sufficient distance from the ground, the Z coordinate in three-dimensional space can be estimated as the distance H between the camera and the ground plane. Based on this, the projected image point (u, v) is on the line intersecting two horizontal vanishing points (u_1, v_1) and (u_2, v_2) . Then we can write a linear equation with respect to T :

$$(u - u_1)(v_1 - v_2) - (v - v_1)(u_1 - u_2) = 0 \quad (15)$$

and

$$-R^{-1}T = \begin{bmatrix} x_c \\ y_c \\ H \end{bmatrix} \quad (16)$$

These equations are sufficient to reconstruct the translation matrix T .

III. PROPOSED ALGORITHM

Based on the video frame image, it is possible to restore the camera parameters. The entire process can be divided into several stages, in which the image vanishing points are first determined, and then the process of calculating the internal and external parameters of the camera. The algorithm proposed in the work assumes the presence of rectilinear objects and information about their mutual arrangement in 3D space. Then the proposed algorithm for restoring internal and external parameters will take the form:

The proposed algorithm for restoring internal and external parameters of the camera

Input data:

1: $H, x_1, x_2, y_1, y_2, m, n, \lambda$

Construction of the equation of lines

Line 1

2: $k_1 = \frac{y_2 - y_1}{x_2 - x_1},$
3: $b_1 = y_1 - k_1 x_1$
4: $y_{c_1} = k_1 x_c + b_1$

Line 2

5: $k_2 = \frac{y_2 - y_1}{x_2 - x_1},$
6: $b_2 = y_1 - k_1 x_1$
7: $y_{c_2} = k_2 x_c + b_2$

Finding the vanishing point

8: $k_1 x_c + b_1 = k_2 x_c + b_2$
9: $V_1(x_c, y_c)$

Determining the coordinates of the image center

point 10: $x_0 = \frac{m}{2}, y_0 = \frac{n}{2}$

Calculating focal length

11: $f_x = \sqrt{(x_c - x_0)^2 + (y_c - y_0)^2}$

Definition of camera projection matrix

12:
$$K = \begin{bmatrix} f_x & 0 & c_u \\ 0 & f_y & c_v \\ 0 & 0 & 1 \end{bmatrix}$$

13: $u = f_x \frac{x_c}{H}, v = f_y \frac{y_c}{H}$

14:
$$\lambda \begin{bmatrix} u \\ v \\ 1 \end{bmatrix} = K \begin{bmatrix} r_{11} & r_{12} & t_1 \\ r_{21} & r_{22} & t_2 \\ r_{31} & r_{32} & t_3 \end{bmatrix} \begin{bmatrix} X_c \\ Y_c \\ 1 \end{bmatrix}$$

Restoring the translation matrix

15:
$$-R^{-1}T = \begin{bmatrix} x_c \\ y_c \\ H \end{bmatrix}$$

Output data:

16: R, P, K, T, f

IV. USING THE TEMPLATE

In order to analyze the efficiency of this algorithm, experimental modeling was carried out. A video recording the traffic situation in Stavropol was used for the experiment. The video was recorded using an ARTWAY AV-712 camera installed at a height of $H=1400$ mm from the ground plane. The video is 37 sec long, with a frequency of 30 fps and a resolution of 2560×1440 . Figure 1 shows frame 1089 from this video. For this frame, we will construct and find three vanishing points.



Fig. 1. Frame 1089 illustrating the traffic situation

Two lines along the left curb will give the vanishing point on the left. Two lines along the right side of the building will give the vanishing point on the right. Two vertical lines of the building will give the vertical vanishing point. The constructed projection lines with the selected vanishing points are shown in Figure 2.



a



b

Fig. 2. Frame 1089 illustrating a) the image grid; b) projection lines for three vanishing points

The calculated coordinates of the three vanishing points are as follows: $(u_1, v_1) = (-298, 471)$, $(u_2, v_2) = (1586, 504)$, $(u_3, v_3) = (1172, 949)$. For further reconstruction of the internal parameters of the camera, we will use the coordinate of the image center $(u_0, v_0) = (1280, 720)$ and the measured camera height $H = 1400$ mm. Then, with the given values, the reconstructed internal parameters of the camera will have the form: $(u_0, v_0) = (1257, 661)$ and $f = 884$ and the rotation and translation matrices will be reconstructed as:

$$R = \begin{bmatrix} -1.4801 & 0.5329 & 0.5841 \\ -0.5311 & -1.9418 & -1.8541 \\ -1.4193 & -0.7974 & -0.8165 \end{bmatrix},$$

$$T = \begin{bmatrix} -2961,196 \\ -5743,883 \\ -5867,854 \end{bmatrix}$$

Table 1 shows the results of the restored camera parameters. The comparison was made with the original values. As can be seen from the table, the restored values of the central point and focal length vary in the range of 1%. The error of the values for the rotation and translation matrices is in the range of 0.0003. Thus, the proposed camera autocalibration algorithm is able to restore the exact parameters of the camera.

TABLE I. RESTORED CAMERA PARAMETERS

Initial camera parameters	Restored camera parameters
x_c	
1280	1293
y_c	
720	727
f	
1400	1415
R	
$\begin{bmatrix} -1,4801 & 0,5329 & 0,5841 \\ -0,5311 & -1,9418 & -1,8541 \\ -1,4193 & -0,7974 & -0,8165 \end{bmatrix}$	$\begin{bmatrix} -1,4803 & 0,5331 & 0,5843 \\ -0,5313 & -1,9421 & -1,8543 \\ -1,4196 & -0,7976 & -0,8167 \end{bmatrix}$
T	
$\begin{bmatrix} -2961,196 \\ -5743,883 \\ -5867,854 \end{bmatrix}$	$\begin{bmatrix} -2961,198 \\ -5743,884 \\ -5867,856 \end{bmatrix}$

V. CONCLUSIONS

This paper presents an applied method of camera autocalibration designed for road video surveillance systems. Knowing only the camera installation height H , it is possible to accurately reconstruct both the internal and external parameters of the camera based on the appearance and trajectories of moving objects in the video stream. The experimental results confirmed the high accuracy and efficiency of the proposed method, which makes it suitable for various video surveillance tasks, including model-based object recognition, basic classification, and image-based metric measurements.

Further research will focus on expanding the proposed auto-calibration method to work in more challenging environments such as multi-level road junctions, dense traffic and variable weather conditions, as well as integrating this method with machine learning systems to automatically improve calibration accuracy and expand the scope of application to include the analysis of the behavior of moving objects.

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The Learning Potential of VR-Technologies in the Educational Process

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Abstract— The problem is the communicative generation of ideas based on IT technologies for the development of new constructive solutions in the field of 3D modeling. Development of creative learning potential. The solution method is a systematic approach to modeling a multidisciplinary platform in an educational environment to find the most appropriate solution using IT technologies, which allows you to find the right solution in the shortest possible time. The result is access to administrative resources: the ability to instantly update information (response speed), build a variable educational trajectory, support an individual educational model, develop creative learning potential and group thinking.

Keywords— *online educational platforms, communication barriers, solid modeling, quality assurance, databases, education, knowledge based systems, educational content, virtual reality, augmented reality*

I. INTRODUCTION

Insufficient attention has been paid to the possibilities of overcoming communication barriers when using VR technologies in the educational process in terms of visibility of virtual models (representations) of professional objects and their impact on the subject of influence.

Today, fundamental discoveries in science provide grounds for the active development of applied research and contribute to the emergence of multidisciplinary approaches in the modern educational process. Such approaches expand the possibilities of building variable educational trajectories while simultaneously activating both group and individual development.

Online educational platforms are currently an integral part of the development of scientific knowledge.

II. THE PURPOSE AND OBJECTIVES OF THE STUDY

Educational resources are platforms that allow students and postgraduates to develop their own skills in VR systems for future unique research. Such skills include:

- Critical thinking;
- Collaboration in a group of students;
- Creativity;
- Digital literacy;

- Communication skills (related to understanding and clarity of information transmission);
- Communication skills (focused on successful relationship building and mutual understanding);
- A systematic approach in integrating the constructions of the past and existing experience into the plans of the future.

The purpose of creating an educational environment model is to train scientific personnel in a multidisciplinary educational environment.

Tasks:

- to study the basic principles and approaches to decision-making in each of the selected disciplines;
- identify the basic requirements and limitations for selected disciplines from different fields of knowledge;
- to identify competence, scientific communication skills as a result of the search for solutions;
- create a model of the platform for finding the most appropriate solution using IT technologies, which allows you to find the right solution in the shortest possible time.;
- use the variability of 3D modeling to obtain the result of a decision based on communication.

III. APPLICATION OF MODELING TECHNIQUES USING A MULTIDISCIPLINARY EDUCATIONAL PLATFORM

With the development of 3D technologies and computing power, even a personal computer, as well as software tools for obtaining the desired results, the time and money spent on obtaining the final results are significantly reduced. Therefore, it is more economically feasible to use such systems in industry.

One of the main advantages of spline modeling is that it does not depend on the visual resolution of the object, that is, theoretically, it is possible to approach arbitrarily close to the object without fear of the effect of stepping. Spline modeling is great for creating complex organic shapes such as human faces, dinosaur carcasses, or models of alien flying saucers.[1]

It is important to get a specific result from an existing project.

Here is an example of using an electric motor model for visual representation of constructive improvement and created in a CAD system using 3D modeling (Figure 1).

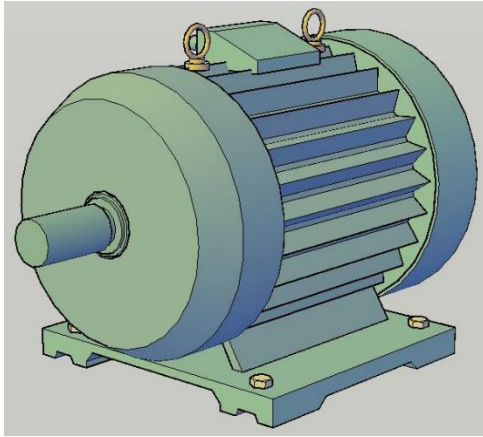


Fig. 1. Visual representation of an electric motor

This object refers to geometric models of three-dimensional bodies represented by shells in the form of grids with triangular cells and having no characteristic parameters that can be modified.[1]

The new object differs from traditional editable grids mainly in that its shells consist not of triangular faces, but of polygons. Each polygon, which is just a polygon, replaces a collection of two or more adjacent triangular faces lying in the same plane.[1]

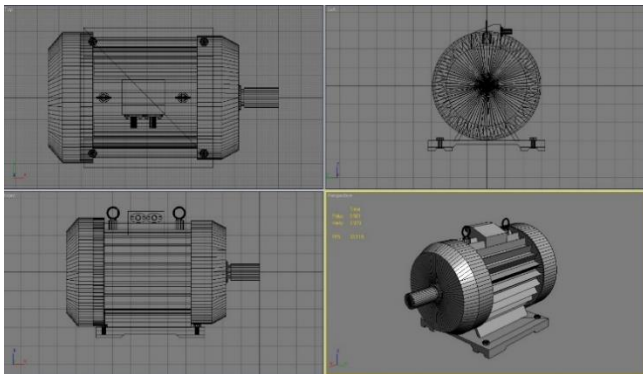


Fig. 2. Transfer of an electric motor model from a CAD system to a visualization program

Modification of the shape of such objects is possible only by editing the mesh itself at the level of vertices, edges, faces, or polygons (Figure 2).[1]

The following illustration shows which coordinates were assigned to which object (Figure 3).

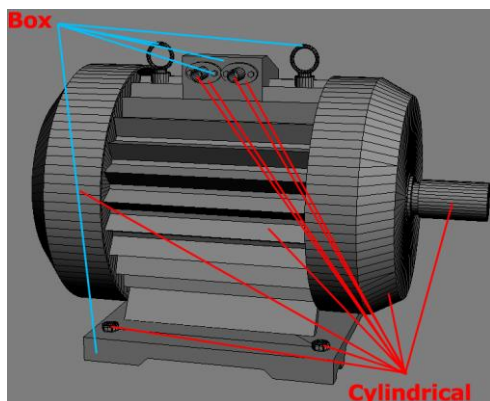


Fig. 3. Matching coordinates to objects

After the texture coordinates are applied, you can start creating view points (camera placement), lighting (light source placement), and general visualization settings.

The default lighting model is an imitation of the light from the observer's eyes, so in any view, the side that is invisible to us is darkened. To make the picture more realistic, you need to arrange the light sources.



Fig. 4. The result of processing for further research using a VR-system

The result obtained (Figure 4) is an excellent example of the possibility of using a combination of the three considered software tools in an enterprise. The use of such methods of product presentation will increase the competitive side of the enterprise through its advertising activities, since, firstly, these programs can be used to create animated videos for subsequent demonstration at exhibitions, conferences and television, and secondly, the use of 3D graphics has become more convenient and relevant over the years, due to the simplification of many tasks. applied tasks.

Advantages of the applied methodology using a multidisciplinary educational platform:

- Visual representation of the product without the cost of prototyping;
- The ability to show the assembly of the product in the form of video material;
- The opportunity to show a product made of any material;
- Possible production of VRL presentations;
- The ability to refine the simulated scene at any stage of its creation.

IV. CONCLUSIONS

The task is to explore the possibility of creating unique educational environments that increase the level of involvement in the study and development of professional skills.

The main function of communication processes is to overcome barriers to achieving a collaborative scientific approach while preserving the individuality of each element.

Eliminating gaps between students and educational resources is a process of overcoming communication barriers.

The article substantiates the construction of multidisciplinary knowledge bases that enable the search for creative and effective solutions based on visual virtual models of professional objects.

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Scientific Foundations of an Intelligent Method for Quality Assessment and Monitoring of Information Content and Digital Security of Public Resources of Educational Organizations

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Abstract—The article considers the procedure of analysis of public resources of educational organizations for compliance with the established requirements of the state and actual needs of users. The existing methods are critically analyzed and their key advantages and disadvantages are identified. A scientific justification for the creation of a new intellectual method of quality assessment and monitoring and an algorithm of work for the creation of a new tool are proposed. The implementation of the method will allow educational organizations to minimize the risk of information distortion or loss and reduce the risk of cyberattacks, ensuring the reliability of digital resources for users.

Keywords—compliance analysis, educational resources, quality assessment, cybersecurity risks, digital monitoring

I. INTRODUCTION

There are more than 126 thousand educational organizations in the Russian Federation, including about 60 thousand comprehensive schools, more than 22 thousand institutions of secondary specialized education, about 31 thousand preschool educational institutions, as well as about 11 thousand institutions of additional education and 1.2 thousand institutions of higher education [1-3]. Under the Federal Law No. 273 of December 29, 2012 "On Education in the Russian Federation", every educational organization is obliged to have a public resource. Legislative acts have been developed to determine the composition and the structure of information content for all public resources [4-6]. Every year, legislative and regulatory documents concerning public resources of educational organizations are filled with new rules and criteria on information content. This is due to the creation of new website sections, the development of new documents, the formation of new requirements for the work of public resources and the development of new activity areas of educational organizations. In addition to the state commitment, having its own public resource is a source of information for the organization's staff and students, as well as a reputation and a way to attract new applicants.

Every year the requirements for information content, security, speed of operation and web usability of public resources become more complex. The requirements for public resources need to be more complex for a number of reasons. Firstly, users are becoming more demanding with the development of technology. They expect fast page loading, user-friendly navigation, adaptive web design and interactivity. Public resources must be ready to provide the user with the best experience to attract and hold his attention. Secondly, with the growing number of devices and different platforms where users view public resources, it is necessary to take into account different screens, resolutions and browsers. Thirdly, the development of web technologies leads to the emergence of new vulnerabilities and threats, and therefore it is necessary to ensure data protection and prevent hacking. Fourthly, with the development of legislation and increased requirements for data confidentiality, public resources must comply with strict rules and standards.

To maintain the current state of public resources within the established requirements and exclude outdated and unsafe technologies, it is necessary to implement monitoring tools with subsequent development of recommendations to address identified deficiencies.

II. ANALYSIS OF EXISTING MONITORING TOOLS

Three program complexes for solving such tasks have been registered in the unified register of Russian programs for electronic computers and databases. The analysis of the registered solutions [7-9], given in Table I, has shown that the existing complexes are not the testing tools of public resources of educational organizations as required by the established information and technical requirements.

TABLE I. ANALYSIS OF PROGRAM COMPLEXES FROM THE UNIFIED REGISTER OF RUSSIAN COMPUTER PROGRAMS AND DATABASES

№	Name	Register entry	Advantages and disadvantages of public resources
1	The monitoring system of the availability and security threats of websites "Monitorus".	No. 15578 of 18.11.2022	Possibilities of this service are limited to determination of several parameters of page loading speed, ip-resource and server response code. Without the ability to work with the content and security. It is impossible to perform a full-fledged analysis of public resources of educational organizations with the help of this service.
2	Software "Scanfactory. Monitoring of websites and servers".	No. 14815 of 12.09.2022	A powerful software system to protect against cyberattacks. A variation of blockchain. It does not work with content and usability.
3	Early detection system of information attacks "L7.Monitoring."	No. 14468 of 08.08.2022	Similar to Scanfactory software, the solution resembles a type of antivirus.

To determine the quality of information content of public resources of educational organizations, state institutions with the help of commercial organizations have developed their own assessment systems, such as "All-Russian Rating of Educational Websites" and "National Foundation for Innovation Support", and presented them in the form of ratings posted on web resources [10-11]. However, it does not make sense to consider them within the framework of this article.

Existing methods for quality assessment and monitoring of security of public resources of educational organizations are often limited to manual checks or the use of simple automated tools, and do not provide the comprehensive approach required for modern educational resources (Table II).

TABLE II. ANALYSIS OF EXISTING APPROACHES TO QUALITY ASSESSMENT AND MONITORING OF SECURITY OF PUBLIC RESOURCES OF EDUCATIONAL ORGANIZATIONS

Assessment method	Disadvantages of the assessment method	Justification of the disadvantage of the assessment method
Manual check	Subjectivity, low processing speed	Manual check depends on an expert opinion, which can lead to inaccuracies. Manual check of a large number of sites is time-consuming
Automated systems	Limited, lack of complexity	Automated tools often assess only the presence or absence of information, ignoring its quality, uniqueness and relevance. Most methods do not take into account such aspects as morphology, grammar, data structure and level of digital security
Rating systems	Lack of complexity	Lack of accounting of digital security, low detailed assessment

These limits make the existing methods inappropriate for effective monitoring and quality assessment of information content and digital security in the context of the growing volume of digital resources, which means that it is necessary to find a new intelligent method that will help to determine the reliability and quality of the submitted data promptly, as well as monitor the entire information and education environment comprehensively.

III. SCIENTIFIC FOUNDATIONS OF THE DATA HANDLER

To develop a new intelligent method for quality assessment and monitoring of information content and digital security of public resources of educational organizations, it is necessary to rely on modern scientific principles and technologies. Such a method should be comprehensive, automated and adaptive to solve the tasks of content analysis, security and improvement of the user experience effectively. The proposed approach is based on the principles presented in Table III.

TABLE III. SCIENTIFIC FOUNDATIONS OF A NEW INTELLIGENT METHOD FOR QUALITY ASSESSMENT AND MONITORING OF INFORMATION CONTENT AND DIGITAL SECURITY OF PUBLIC RESOURCES OF EDUCATIONAL ORGANIZATIONS

Technologies	Justification of technology choice
Natural Language Processing (NLP)	Using NLP to analyze textual content, including semantic analysis, assessment of grammar, style and uniqueness
Machine Learning	Applying machine learning algorithms to classify data, identify patterns and predict content quality
Cybersecurity	Using methods of vulnerability analysis to assess the level of data protection and compliance with security standards
Automation and Scalability	Applying of computer-aided technologies to process large amounts of data in short timeframes
Integrated assessment approach	Assessment of not only textual content, but also the site structure, ease of navigation, accessibility to disabled people
Dynamic monitoring	Regular updating of data and analysis of changes on websites to ensure the relevance of assessments
Utilization of cloud technologies	Utilizing cloud-based storage and processing platforms for high performance and availability
Data visualization	Generating reports using graphs, charts and other visualization tools for easy perception
Integration with existing systems	Ability to integrate the method with educational resource management platforms (e.g., Moodle, 1C-Bitrix)
Ethics and data protection	Compliance with the principles of confidentiality and protection of personal data when analyzing and processing information

To determine the compliance of public resources of educational organizations with the established requirements, it is necessary to create a scientific basis for a data handler based on artificial intelligence methods. The handler will receive input data divided into textual, graphical and technical parts to be analyzed on the basis of a number of conditions.

The text part entering the handler is a data set which has content information in text format, the graphics part is a data set related to images, and the technical part contains data related to safety and technical characteristics. Both sets are represented as xml/csv files.

The following requirements and regulations are used to process the input data [12-17]. Based on these rules, the initial file check is performed for compliance with the parameters: appropriate file extension, correct structure and encoding. Then the data is exported to the handler for operations related to direct data processing.

All processed information is displayed on a separate web page with limited access, which will be available only to the user who created the page. A “share” button is provided for other users to view the generated page.

To create the scientific foundations of the data handler, it is necessary to formalize the work of its mathematical apparatus, for example, in the form of a blackbox model (Fig. 1).

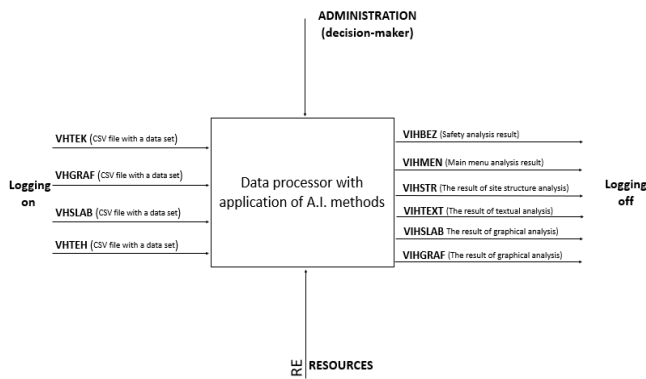


Fig. 1. The system activity represented by the black box method.

We formalize the input data in a structured and well-defined form:

VHTEK – a set of text obtained by site parsing (1)

$VHTEK = \langle GIMenu, MSilk, NDoc, Inf, GSilk \rangle$, (1)

where GIMenu – upload of the home menu structure of a public resource of an educational organization as an xml/csv file.

MSilk – a link array on the pages of interest.

NDoc – a data array with document titles (text, graphic, tabular) with extensions.

Inf – a data array with general information about the organization recommended for the mandatory posting.

GSilk – a list of links to government resources.

VHGRAf – a set of graphics data obtained by site parsing (2).

$VHGRAf = \langle Jpeg, Gif, Png, Svg \rangle$, (2)

where Jpeg – a link array to images in .jpeg format as a csv file.

Gif – a link array to images in .gif format as a csv file.

Png – a link array to images in .png format as a csv file.

Svg – a link array to images in .svg format as a csv file.

VHTSLAB – a set of text obtained by site parsing (3)

$VHSLAB = \langle Shrift, Intstr, Intlet, Color, Img \rangle$, (3)

where Shrift – upload with available font settings as xml/csv file.

Intstr – upload with available line spacing settings as xml/csv file.

Intlet – upload with available letter spacing settings as xml/csv file.

Color – upload with available color settings as xml/csv file.

Img – upload with available settings for image correction as xml/csv file.

VHTEH – a set of technical data obtained by site parsing (4).

$VHTEH = \langle Guard, Func, Func2 \rangle$ (4)

where Guard – security parameters (ssl featuring, a core assessment, site affiliation to the Russian server, check for compliance with the Federal Law “On Personal Data” No. 152).

Func – a mandatory feature (a visually-impaired version, a site map).

Func2 – general (widgets and graphics).

We formalize the output data to bring it to a common format:

VIHBEZ – an output array obtained by processing of the input security data by the handler (5).

$VIHBEZ = \langle Kods, Ssl, Yadro, Host, Fz152 \rangle$, (5)

where Kods – a server response code.

Ssl – featuring of ssl certificate.

Yadro – an assessment result of the site core.

Host – site affiliation to the Russian server.

Fz152 – assessment results of the application of the Federal Law “On Personal Data”.

VIHMEN – an output array obtained by the input data processing by the menu handler (6).

$VIHMEN = \langle Sved, Struct, Stand \rangle$, (6)

where Sved – test results of base information.

Struct – an assessment result of the structure and authorities of an educational organization.

Stand – a compliance analysis of an educational organization and requirements.

VIHSLAB – an output array obtained by the input data processing connected with the visually-impaired version by the handler (7).

$VIHSLAB = \langle OptN, OptW \rangle$, (7)

where OptN – a quality check result of necessary settings.

OptW – an operability check result of the detected settings.

VIHSTR – an output array obtained by the input data processing connected with the structure of the public base of an educational organization by the handler (8).

$$\text{VIHSTR} = \langle \text{Amass}, \text{Atech} \rangle, \quad (8)$$

where Amass – an assessment result of the link structure, in accordance with the documentation regulating the information content.

Atech – a technical assessment of the operability of the link array.

VIHTEXT – an output array obtained by the input data processing connected with the content by the handler (9).

$$\text{VIHTEXT} = \langle \text{Token}, \text{Lemma}, \text{Semant} \rangle, \quad (9)$$

where Token – an assessment result of the function and context of individual words in sentences.

Lemma – an assessment result of content uniqueness.

Semant – an assessment result of grammar, style, uniqueness and relevance to key topics.

VIHGRAF – an output array by the input data processing connected with the home page by the handler (10).

$$\text{VIHGRAF} = \langle \text{Aimg}, \text{Aflash} \rangle, \quad (10)$$

where Aimg – the result of image quality check.

Aflash – presence/absence of flash technologies.

Lets describe the resources mathematically as a set of RE (11).

$$\text{RE} = \langle \text{ReglDoc}, \text{Tech}, \text{TServ}, \text{Int}, \text{Slovar}, \text{Inp}, \text{Slab}, \text{Dom}, \text{Obr}, \text{Out}, \text{BD1}, \text{BD2} \rangle, \quad (11)$$

ReglDoc – regulatory documentation for information content (GOSTs, Federal Laws, Orders);

Tech – a checklist for the technical security of the organization's public resource.

TServ – requirements to the technical equipment of the virtual server.

Int – Internet connection requirements (only from the Russian Federation).

Slovar – dictionaries: spelling, grammar.

Inp – requirements for source xml/csv files.

Slab – requirements for visually-impaired version.

Dom – domain name requirements.

Obr – file processing and recording requirements.

Out – information output requirements.

BD1 – a database with GOSTs, Federal Laws and methodologies.

BD2 – a database for recording results.

IV. ALGORITHM OF THE SOFTWARE OPERATION

Based on the listed scientific principles and technologies, it is possible to form an algorithm of work and functional block diagrams of software that will provide comprehensive assessment and monitoring of information content quality

and digital security of a public base of an educational organization. Below is a detailed description of the stages of this algorithm:

1. Data collection. At the initial stage, data is collected from a public resource of an educational organization using web scraping technologies. Parsing includes textual content extract, technical information and information about site navigation. In case of errors, parsing is repeated until successful completion. As a result of the parser's work, a CSV file with the input data for the intelligent data handler is generated at the output (Fig. 2).

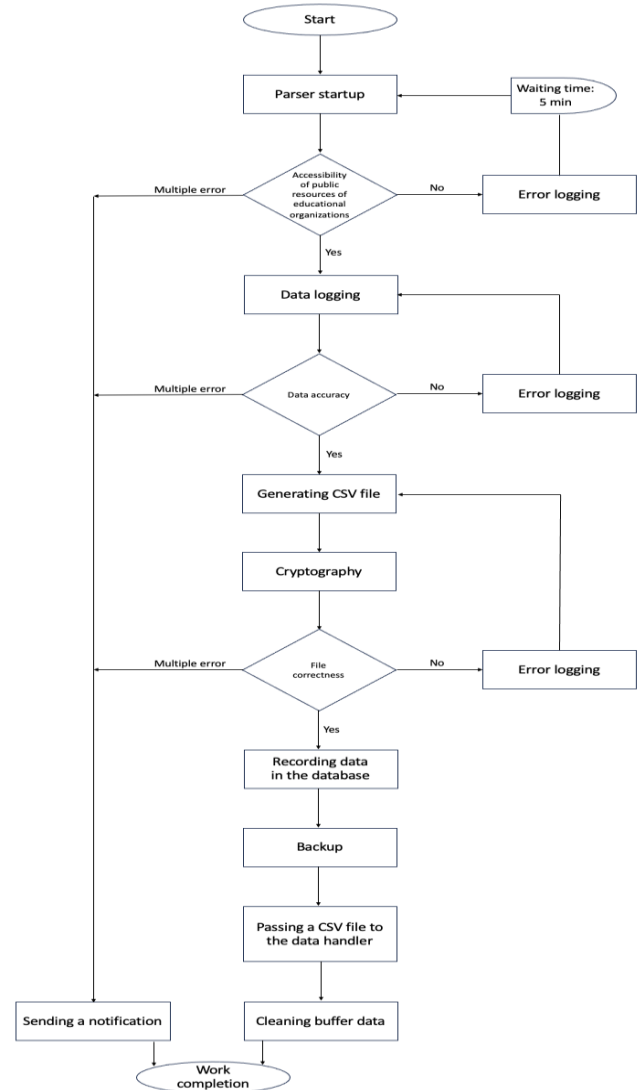


Fig. 2. Block diagram of data collection from a public database of an educational organization

2. Data processing (Fig. 3)

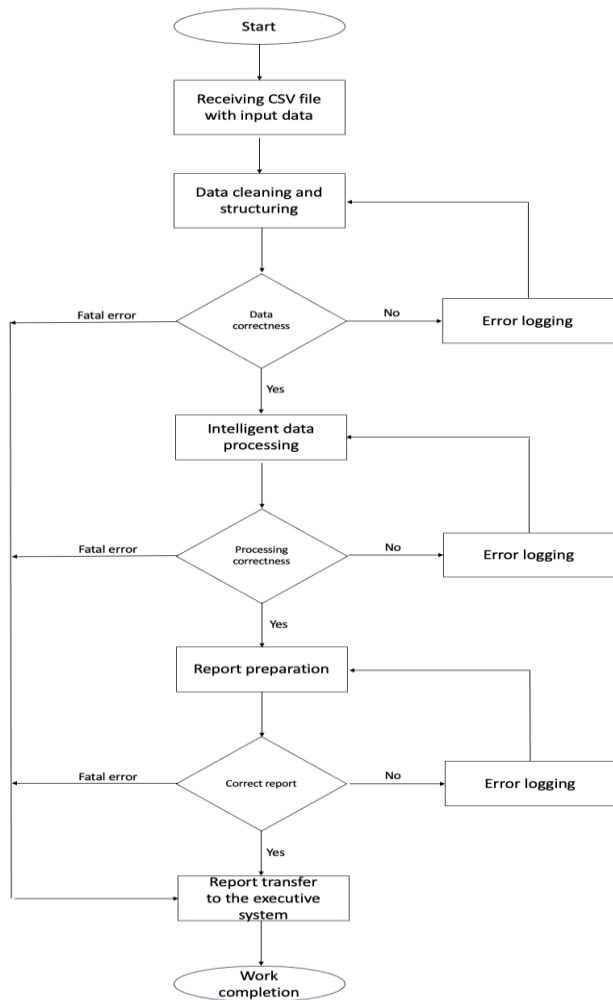


Fig. 3. Block diagram of functioning of the intelligent data handler

2.1 The collected data is cleaned and structured. This stage removes duplicates, corrects formatting errors and brings the data to a common standard. If the data contains much noise or mismatching, parsing is repeated. Textual content is analyzed by natural language processing (NLP). Tokenization, lemmatization, and semantic analysis are performed to assess grammar, style, uniqueness and relevance to key topics. If the content does not meet the established quality criteria, a note of improvement is generated and the data is passed to the report generation stage.

2.2 The site navigation and accessibility for users, including disabled people are assessed. The compliance with WCAG (Web Content Accessibility Guidelines) principles is checked. If the site structure does not meet the standards, it is recorded in a report with recommendations for improvement.

2.3 This stage analyzes security clearance and cybersecurity standards compliance. SSL certificates are checked, vulnerabilities are identified, and regulatory compliance is assessed. If critical vulnerabilities are detected, the information is passed to the report generation stage, indicating necessary prompt corrections.

3. Report formation. A report is formed on the data obtained at the previous stages. It includes data visualization and recommendations for improving content quality, site

structure and security level. If the report cannot be formed due to errors in the data, the process returns to the text content analysis stage for re-checking.

4. Integration with executive systems. Executive systems of educational resources automatically get reports and administrators learn about identified problems. The process returns to the report generation stage for a retry if there are data connection errors.

5. Process completion. The process is completed after successful data connection. All stages of the method are documented, so it possible to monitor if recommendations are followed and to improve the quality of educational organizations' websites.

The development of online service is important for updating the information content and security of a public base of an educational organization. For example, from 1st September, 2024, new requirements for the structure of the official public resource of an educational organization in the information and telecommunication network "Internet" and the format of information presentation came into force [18]. This means that a public base of an educational organization requires changes again.

The scientific basis of a new intelligent method includes mathematical apparatus of a data handler, an algorithm and functional block diagrams of a software required to perform tasks. The new method meets all the given conditions. The advantages of the new intellectual method of quality assessment and monitoring of information content and digital security of a public base of an educational organization are presented in Table IV.

TABLE IV. ADVANTAGES OF THE NEW INTELLIGENT METHOD OF QUALITY ASSESSMENT AND MONITORING OF INFORMATION CONTENT AND DIGITAL SECURITY OF A PUBLIC BASE OF AN EDUCATIONAL ORGANIZATION

Condition	
Comprehensiveness	Quality assessment of all aspects of information content and digital security. Usability feature and level of security clearance
Automation	Significant reduction of verification time. Elimination of the human factor
Adaptability	Ability to process large data volumes when necessary, which is especially important for monitoring sites on a regional or national scale

The new assessment system will be useful for site population to ensure information actuality, for moderators - to facilitate self-checking, for developers - to control technical changes, and for educational organizations' authorities - to enhance their reputation. The new assessment system has the following features:

- Ability to quality assessment of information content of a public resource of a government institution without human input.
- Automation of quality assessment of public resources for inspection bodies.
- Functional availability for self-control of resource managers.
- Control of syntactic and spelling errors when filling content.
- Errors exception when filling with graphic elements.

- Increasing the speed and better assessment of information content.
- Control over completeness of information required for placement.
- Quality improvement of information content of public resources of educational organizations for all categories of the Russian education system.

Table V presents a comparative analysis of the existing methods of quality assessment and monitoring of information content and digital security of a public base of an educational organization with the one proposed in the article.

TABLE V. COMPARATIVE ANALYSIS OF THE EXISTING METHODS OF QUALITY ASSESSMENT AND MONITORING OF INFORMATION CONTENT AND DIGITAL SECURITY OF A PUBLIC BASE OF AN EDUCATIONAL ORGANIZATION WITH THE ONE PROPOSED IN THE ARTICLE

Criteria	Manual inspection	Automated Systems	Rating systems	Proposed method
Speed of analysis	Low	Medium	Low	High
Objectivity	Medium	Medium	Low	High
Complexity	Medium	Medium	Medium	High
Scalability	Low	Medium	Medium	High
Flexibility	Low	Low	Medium	High

V. CONCLUSIONS

In the course of the work it has become possible to create mathematical apparatus of the data handler in the form of the blackbox model for processing and analyzing a public base of an educational organization in relation to the given criteria. The algorithm of a web service and functional block diagram were developed to apply the data handler in practice.

The obtained result made it possible to form the scientific basis of the intellectual method of assessment and monitoring of information content and digital security of a public resource of an educational organization, necessary for the development of a software solution. Such solution is required to maintain the current state of a public resource of an educational organization within the established requirements and exclude outdated and unsafe technologies. It will provide a comprehensive assessment and monitoring with the further recommendations to address the identified shortcomings.

The software solution has the following capabilities: it assesses all existing types of educational websites, has tools to analyze necessary pages, checks text information according to the rules of the Russian language and searches for errors made due to human factor. It assesses graphic images for malicious advertising and virus encapsulations, and also assesses digital security parameters under specified requirements. It is fully automated and with the ability to adjust the algorithm when the government changes assessment criteria.

Prospects for future research are:

- Expansion of functional by analysis of multimedia content (video, audio).
- Integration with executive systems for automatic generation of reports and recommendations for site administrators.
- Development of mobile applications for easy real-time monitoring and analysis.

- Assessment of sites accessibility for disabled people (e.g., WCAG compliance).
- Development of APIs for integration with existing platforms of educational resources management.

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Modeling of Wireless Sensor Network Clustering by Constructive Neural Network Method

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Abstract— With the development of Internet of Things technology, a wireless sensor networks (WSNs) as the basis for Internet of Things technology has emerged. These networks utilize technologies that underpin the development of healthcare, sports, and other applications. Routing in WSNs encounters a number of challenges due to the characteristics that distinguish these networks from other wireless networks. Routing protocols must address these challenges in order to reduce energy consumption and optimize the use of energy resources. Currently, a number of algorithms have been proposed to address these challenges, including those that take into account the clustering of WSNs. The paper presents the results of modeling the clustered structure of WSNs based on the radio visibility matrix obtained using the constructive neural network method.

Keywords— wireless sensor networks, routing protocols, clustering, neural networks, self-organization networks

I. INTRODUCTION

With the development of Internet of Things technology and ubiquitous sensor networks, a new type of network, wireless wearable body sensor networks (WWBSNs or BSNs), has emerged as the basis for Internet of Things technology [1,2]. These networks are wireless sensor nodes located around the human body, and these nodes communicate with each other and with a central node (coordinator) based on the IEEE 802.15.6 standard. These networks utilize technologies that underpin the development of healthcare, environmental, sports and other applications [3-9].

These networks are also characterized by very low transmission power to reduce power consumption, high data rate to ensure quality of service, and are characterized by low cost and small size. The most common sensors are EEG “Electroencephalography”, ECG “Electrocardiogram” and EMG “Electromyography” [10].

The BSN architecture consists of a coordinator that acts as a gateway and enables communication between BSN nodes, sensor nodes that monitor certain parameters and enable human monitoring at all times, and communication links for information that is collected and transmitted via Internet/NGN to the base station, as shown in Fig.1, for monitoring, control, processing, etc.[11].

In the Department of Intelligent Systems in Control and Automation at Moscow Technical University of Communications and Informatics (MTUCI), a significant body of research has been conducted on the applications of the Internet of Things, robotics, and machine learning [12,13].

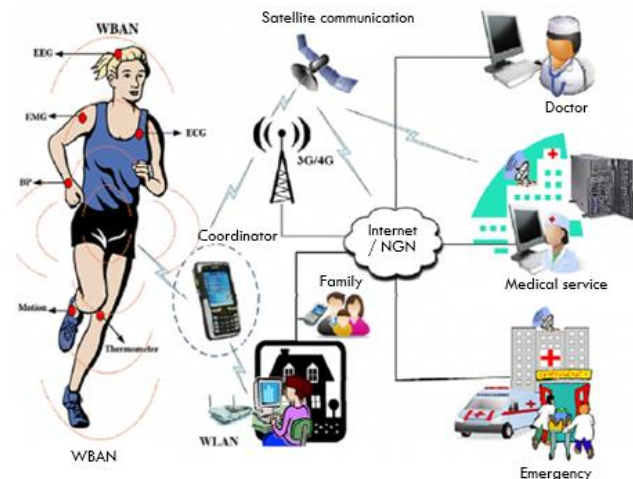


Fig. 1. Architecture of Wireless Wearable Body Sensor Network.

Routing is one of the major challenges in wireless sensor networks related to finding the optimal path for data transmission from source to destination. In general, a number of important issues need to be considered in the design of any routing algorithm such as self-regulation, energy efficiency, flexibility, scalability, fault tolerance, accuracy and quality [14,15]. Routing protocols for WSNs can be classified into seven categories as shown in Table I.

TABLE I. CATEGORIES OF ROUTING PROTOCOLS FOR WSNs

Category	Protocols
Node location	MECN, SMECN, GAF, GEAR, Span, BVGF, GeRaF
Data aggregation	SPIN, Directed Diffusion, Rumor Routing, COUGAR, ACQUIRE, EAD, Information-Directed Routing, Gradient-Based Routing, Energy-aware Routing, Quorum-Based Information Dissemination, Home Agent Based Information Dissemination
Hierarchical	LEACH, PEGASIS, HEED, TEEN, APTEEN
Mobility	SEAD, TTDD, Joint Mobility and Routing, Data MULES, Dynamic Proxy Tree-Base Data Dissemination
Multi-oriented	Sensor-Disjoint Multipath, Braided Multipath, N-to-1 Multipath Discovery
Heterogeneity	IDSQ, CADR, CHR
Quality of Service (QoS)	SAR, SPEED, Energy-aware routing

Data transmission methods in a WSN are chosen according to the intended application. Many studies have proven the efficiency of hierarchical routing protocols in

reducing energy consumption and extending the lifetime of the WSN, especially cluster-based routing protocols.

Mainly, hierarchical routing is playing a major role in routing data to the base station by identifying cluster head nodes that transmit data. Thus reduces the number of paths for data transmission and reduces the load on the network [16-19].

In the clustering process, the following tasks should be solved [20]:

1. Defining the set of cluster objects (groups of WSN nodes that are considered as traffic sources);
2. Defining the properties of clustering objects (location of nodes, i.e., the coordinates of nodes in two- or three-dimensional space and their radio visibility)
3. Defining the purpose of clustering (defining the structure of the access network, i.e., selecting the coordinates of cluster head nodes (CH), which are considered as intermediate nodes for access to the gateway/base station)
4. Defining the criterion of cluster allocation - requirements or conditions for the separation of network nodes to assess the proximity of the characteristics of objects within the formed clusters, such as: the maximum number of clusters, cluster size, the number of nodes in clusters and others (in our case, a given number of clusters is allocated).

The author uses the Kohonen network learning algorithm with Constructive method to implement traffic optimization problems in a wireless sensor network with stationary sensor nodes. In clustering, the approach is based on the use of radio visibility matrix.

II. MATHEMATICAL DESCRIPTION

A. Mathematical description of WSNs nodes and radio visibility matrix

In WSN, each node is connected to its neighbors when they are within the node's radio visibility. Thus, each node has its own eigenvector that represents its relationship with the other nodes in the network depending on the distance between nodes and their coverage.

Based on the location of sensors and their sensing range, we can obtain the radio visibility matrix of the WSN, which defines the communication mechanism of the sensors between them, i.e., identifies the sensors that are physically connected to each other.

The radio visibility matrix or proximity matrix is an n th order square matrix describing the communication between nodes in a wireless network, where each node is assigned a proximity to its neighbors. If a neighbor is out of range of a node, it is assigned 0. If the neighbor is within the range of the node, then the proximity is determined by calculating the distance between the node and its neighbor.

So, each value in the radio visibility matrix represents proximity of a node to another node. Proximity value from one i -node to j -node is calculated using this formula.

$$P_{ij} = \begin{cases} 100 - \frac{100 * d(i, j)}{r}; & \text{if } d(i, j) \leq r \\ 0; & \text{if } d(i, j) > r \end{cases} \quad (1)$$

$$d(i, j) = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} \quad (2)$$

where: r – coverage radius of the i -node; $d(i, j)$ – distance between i -node and j -node.

For simplicity, the maximum proximity is considered to be 100, so the values should be in range between $[0, 100]$. A node's proximity to itself is the highest value “100” in the matrix, while its proximity to other nodes is in the range $[0 \dots 99]$.

Mathematically, the radio visibility matrix according to proximity of node is described as follows:

$$\begin{aligned} \bar{P}_i \in Z_i = \{p\} \in \{z\} = p_1 \in z_1, \dots, p_j \in z_j, \dots, p_L \in z_L \\ \forall q_i \exists Z_i \in q_i : (p_1 \in z_1, \dots, p_j \in z_j, \dots, p_L \in z_L) \in q_i \end{aligned} \quad (3)$$

In this way, the connectivity of nodes and the radio visibility of each node with respect to the other nodes can be modeled using the so-called radio visibility matrix P .

$$P = \begin{bmatrix} 100 & P_{12} & P_{1j} & \dots & P_{1n} \\ P_{21} & 100 & \dots & P_{2j} & \dots & P_{2n} \\ \dots & \dots & \dots & \dots & \dots & \dots \\ P_{j1} & P_{j2} & \dots & 100 & \dots & P_{jn} \\ \dots & \dots & \dots & \dots & \dots & \dots \\ P_{n1} & P_{n2} & \dots & P_{nj} & \dots & 100 \end{bmatrix} \quad (4)$$

$$P_{ij} = \begin{cases} P_{ij}, & \text{if } i \neq j \\ 100, & \text{otherwise} \end{cases}$$

where $P_{ij} \in [0 \dots 100]$.

The first row in radio visibility matrix means the radio visibility of the first node with respect to the other nodes. The second row means the radio visibility of the second node with respect to the other nodes and so on.

Based on the analysis related to current methods and algorithms for data transmission in WSNs, there are several types of clustered-based routing protocols. In this paper, the author focused on developing protocols using data mining techniques and machine learning algorithms such as Kohonen network learning algorithm with constructive method [21,22].

B. Kohonen network training algorithm with Constructive Method (KNCM)

One of the clustering methods chosen for this study is based on the Kohonen network learning algorithm with Constructive Method and is based on the representation of nodes as a radio visibility matrix P .

After forming the radio visibility matrix P , it should be normalized using the following formula:

$$P_{NORM} = P / P_{max} \quad (5)$$

where $P_{max} = 100$.

Network **NET** used for clustering depends on the following parameters:

$$NET(N, K, \alpha_0, \tau, R, \mathcal{E}, \{L_j\}) \quad (6)$$

where: N - number of input neurons equal to the number of nodes in the network; K - output neurons equal to the number of clusters; α_0 - initial value of the learning rate; and decreases

with time; τ - constant of training time; R - sensitivity radius; $\mathcal{E}$ - training accuracy; $\{L\}$ - training sample, equal to P_{NORM} .

Using these parameters, the formation of clusters by constructive method is as follows and consists of six steps:

1. The rows of the radio visibility matrix are fed as training vectors to the input of the neural network.

2. In case of the first operation of the neural network there is only one neuron and its weights are initialized with the values of the first row of the radio visibility matrix, then move to step 1, otherwise move to step 3

3. The Euclidean distance is calculated by formula (7) between the current input vector and the weights of each neuron, and then the smallest distance that represents the winning neuron (or cluster) for the current input vector is selected.

$$d(x, w_i) = \|x - w_i\| = \sqrt{\sum_{j=1}^n (x_j - w_{ij})^2} \quad (7)$$

$$d(x, w_i) \leq \sqrt{N} * R \quad (8)$$

4. If the Euclidean distance between the winning cluster and the input vector $d(x, w_i)$ does not satisfy the condition (8), a new neuron will be added to the neural network, and its weights will be the values of this input vector, and then move to step 1.

5. The weights of the winning cluster and the learning rate coefficient are updated by the formula (9, 10):

$$w_i^{t+1} = w_i^t + \alpha(t) \cdot (x - w_i^t) \quad (9)$$

where w_i^t - vector of weights of the i^{th} neuron, t - number of training iteration, x - input vector, $\alpha(t)$ - the learning rate coefficient.

$$\alpha(t) = \alpha_0 * \exp\left(-\frac{t}{\tau}\right) = 0.7 * \exp\left(-\frac{t}{1000}\right) \quad (10)$$

6. In case the current training vector is the last one, if the weights of each neuron change by more than $\mathcal{E}$ compared to the previous case (The final weight matrix will not change at each training iteration if the weights of each neuron change by less than $\mathcal{E}$), then the training of the neural network stops, otherwise move to step 1 and training continues again from the first training vector.

III. EXPERIMENTS

The following experiments on modeling clustering methods were conducted on a personal laptop with the following characteristics: processor - intel Core 3-2328M, 2.2 GHz; RAM - 8GB; operating system - Windows 11 Pro 64-bit. The programs were developed in Python environment, using libraries Pandas, NumPy, Sklearn, Matplotlib, ipywidgets.

To analyze the possibility of clustering, the author developed a program that combines Kohonen network with the constructive method (KNCM), using the radio visibility matrix as a connectivity factor. In the experiments, it is assumed that the sensors in the coverage area are randomly distributed, resulting in a radio visibility matrix that provides connectivity between sensors. The following simulation results for six experiments with different cluster sizes with

sensing radius R equal to (0.26, 0.28, 0.30, 0.32, 0.34, 0.36) are carried out using formula 6.

The following parameters are used as input of all experiments: N - 100 nodes; The radio visibility matrix P is shown in Fig.2.

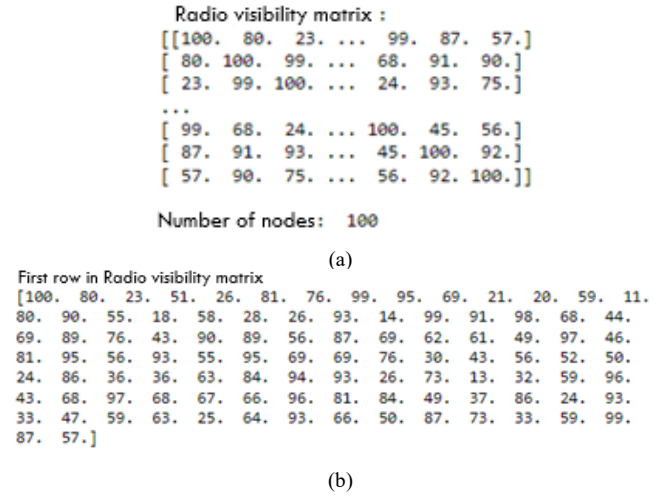


Fig. 2. Representation of the radio visibility matrix: (a) radio visibility matrix, (b) first row from the radio visibility matrix.

Fig.2(a) shows the obtained radio visibility matrix measurements. Fig.2(b) shows the first row obtained from the radio visibility matrix. The first row represents the vector of proximity range the first node is to other nodes in the network. Value "100" represents the radio visibility of the first node to itself and represents the highest value while other nodes fall in the range [0...99].

A. Experiment 1

In this experiment, the sensitivity radius $R = 0.26$ is set. During training of the neural network, the matrix rows are fed to it as input vectors. The neural network runs using the following parameter values from formula (6): NET (P_{NORM} , $N = 100$, $R = 0.26$, $\alpha_0 = 0.7$, $\mathcal{E} = 0.1$, τ). The values of R , α_0 , $\mathcal{E}$ were chosen according to the recommendations of [23]. The number of formed clusters based on the node radio visibility matrix and the parameters set in experiment 1 is 96 clusters.

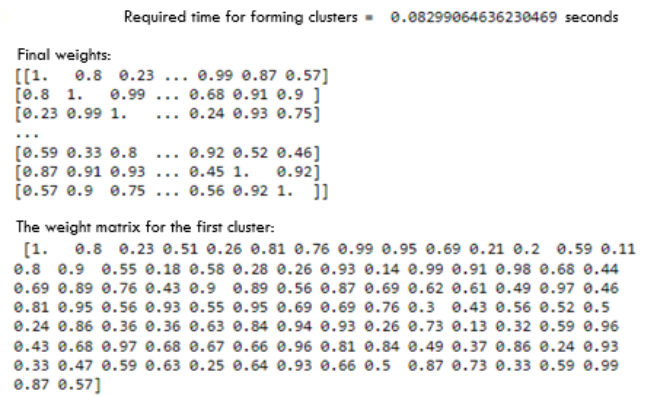


Fig. 3. Final membership weights for each cluster ($R = 0.26$).

Fig.3 shows the final weights obtained in the Kohonen neural network with constructive method after training, which contains the matrix of weights for each cluster, and the cluster formation time, which is approximately 0.083 seconds.

Each cluster that is formed contains a matrix of weights, which in turn contains the probability of each node in WSN belonging to that cluster. Then, the node with the highest

probability in a cluster from one of the formed clusters is added to that cluster.

B. Experiment 2

The sensitivity radius of the cluster is $R = 0.32$. The neural network is run with the following initialized parameter values from formula (6): **NET** (P_{NORM} , $N = 100$, $R = 0.32$, $\alpha_0 = 0.7$, $\mathcal{E} = 0.1$, τ). As a result, a matrix of weights is obtained that determines whether a node belongs to a particular cluster. The formation time of possible clusters, is approximately 0.034 seconds. Fig.4 shows the number of clusters obtained and the belonging of the first ten nodes to the clusters.

Number of clusters : 8
Node 1 is located in cluster 1
Node 2 is located in cluster 2
Node 3 is located in cluster 6
Node 4 is located in cluster 6
Node 5 is located in cluster 5
Node 6 is located in cluster 6
Node 7 is located in cluster 6
Node 8 is located in cluster 8
Node 9 is located in cluster 6
Node 10 is located in cluster 6

Fig.4. Number of clusters and example of node distribution among clusters.

C. Experiment 3

The sensitivity radius of a cluster is $R = [0.28, 0.30, 0.34, 0.36]$. After training the neural network using the following parameter values from formula (6): **NET** (P_{NORM} , $N = 100$, $R = [0.28, 0.30, 0.34, 0.36]$, $\alpha_0 = 0.7$, $\mathcal{E} = 0.1$, τ), the number and required time for formation of clusters are obtained for different values of R :

- if $R = 0.28$: the number of clusters is 61 and the time is 0.048 seconds.
- if $R = 0.30$: the number of clusters is 21, the time is 0.047 seconds.
- if $R = 0.34$: the number of clusters is 3, the time is 0.032 seconds.
- if $R = 0.36$: the number of clusters is 1, the time is 0.032 seconds.

The similar experiments to analyze the clustering by the **KNCM** were carried out for other numbers of nodes: 250, 500 and 1000 at the input, using the whole range of R values from 0.26 to 0.36 with step 0.02. The obtained results of training the Kohonen network with the constructive method on different number of nodes (N) and different values of cluster size (R) are shown in Table II.

TABLE II. EXPERIMENTAL RESULTS FOR DIFFERENT SIZED CLUSTERS FOR DIFFERENT NUMBER OF NODES

N	Number of nodes (N)	Running time (t), sec.						Number of clusters (K)					
		$R = 0.26$	$R = 0.28$	$R = 0.3$	$R = 0.32$	$R = 0.34$	$R = 0.36$	$R = 0.26$	$R = 0.28$	$R = 0.3$	$R = 0.32$	$R = 0.34$	$R = 0.36$
1	100	0.083	0.048	0.047	0.034	0.032	0.713	96	61	21	8	3	1
2	250	0.43	0.35	0.18	0.11	1.77	1.83	250	236	55	7	1	1
3	500	7.98	8.5	2.12	0.3	3.78	3.74	500	500	206	6	1	1
4	1000	49.8	50.9	46.6	0.89	9.34	11.22	1000	1000	854	6	1	1

As experiments have shown there is a strong dependence of the size of the resulting clusters, and hence their number on the parameter R - the radius of sensitivity, which is indirectly related to the radio visibility matrix. It is not possible to unambiguously determine the optimal number of clusters, at which the energy loss during packet transmission will be minimal and the network lifetime will be maximized.

IV. CONCLUSIONS

Clustering is one of the mechanisms that helps to reduce energy consumption in wireless sensor networks and also provides network scalability by limiting the traffic between clusters. The results of neural network modeling that provides a clustering mechanism for wireless sensor networks based on radio visibility matrix using Kohonen neural network with constructive method (**KNCM**), depending on the locations and coverage of these nodes are presented. This mechanism helps in designing clustered-based routing protocols.

In experiments, for clusters with different numbers of nodes, we observed that **KNCM** was able to form clusters based on the size of the cluster to be formed. The larger sensitivity radius of a cluster, the more nodes in it and thus fewer clusters are formed, while the smaller sensitivity radius of a cluster, the fewer nodes in it and thus more clusters are formed. The radio visibility array or proximity array also played a major role in cluster formation by checking for connectivity between nodes within the cluster.

In the future, it is planned to take into account the dynamic network topology, mobile nodes, energy consumption, along with the radio visibility matrix.

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The Impact of Digitalization on the Academic Environment

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Abstract: Academic successfulness of students is one of the indicators of efficiency and quality of the educational process. The article focuses on the academic environment as one of the factors affecting academic successfulness of students. It is acknowledged that due to digitalization all the elements of the academic environment such as infrastructural, societal and axiological have undergone significant changes which, in turn, have had an impact on the efficiency of the academic process and the quality of the educational result. The authors provide some research results on the attitudes of STEM students towards digitalization of various elements of the academic environment, give examples of positive and negative effects of digital innovations, analyze some consequences of introducing digitalization into educational practices and teaching and learning strategies and practices. The authors point out to the importance of the role of the teacher in estimating the effects of innovations introduced into students' learning and academic activities for the proper development of their cognitive and professional competences in the conditions of digitalization.

Keywords: *Academic Environment, Digitalization, Generative Artificial Intelligence.*

I. INTRODUCTION

The issues of increasing efficiency and ensuring the quality of the educational process at different levels have always been important both for researchers, teachers and other stakeholders of the pedagogical process. Various criteria and indicators of the quality of the educational process have been developed, and various factors affecting the quality of organizing and carrying out the educational process, the conditions under which it is carried out and the quality of the educational results have been considered.

Some of the most frequently used indicators of the quality of the educational process are the academic successfulness and the academic achievements of students. The academic successfulness (or academic success) is a complex measure of the academic activities of students which includes both objective and subjective indicators [1]. Among the objective factors there are academic achievements expressed in course or assignment grades or GPA, attainment of the target competences and skills, engagement in academic activities etc. The subjective indicators are those that are related to the attitude of students to their academic achievements, their satisfaction with their academic and educational activities etc. [2]. Encouraging academic success or overcoming academic failure has been seen as one of the major goals of educational institutions of different levels, so great attention has been paid to ways of overcoming academic failure of students and to factors affecting or related to academic success [3]. Many researchers believe that one of such factors is the academic environment of students.

II. LITERATURE REVIEW

Factors affecting or related to academic success or failure of students can generally be broken into two major groups a) individual qualities or characteristics of students, and b) qualities and characteristics of the academic or learning environment developed at the educational institution the students belong to. A lot of research has been devoted to the analysis of the role of such personal characteristics and features of the students as self-discipline, self-organization, motivation, dedication and enthusiasm, in their academic success [4]. Along with that it has been noted that the impact of the environment is not determining, and the effect of the environment on the students is also dependent on their psychological characteristics [5, 6]. It is believed that of all the factors determining academic success only 32% can be attributed to the environment as a whole; moreover, the impact of the academic or educational environment is estimated to constitute 20%, and the remaining 12% fall upon such factors as hobbies and interests, family background, family income, family involvement etc. [7]. However, there is an opinion that the potential of the academic environment and the level of its impact on the students has not been fully researched and is, therefore, underestimated.

In modern philosophy and sociology social environment is defined as a combination of "the immediate physical surroundings, social relationships, and cultural milieu within which defined groups of people function and interact" [8, p.465]. These milieus impact the formation and the development of a human personality, can encourage a certain activity of an individual, increase the potential and improve the results of a given activity. On the other hand, the milieu can affect the individual and their activities in a negative way - interfere with the activities the individual is engaged in, hinder them, decrease their efficiency, degrade the individual's performance [9]. An academic or educational environment is a subsystem of a social environment, so it possesses all its main features, characteristics and qualities. An educational or academic environment encompasses a combination of physical, social, cultural and specially organized psychological and pedagogical setting in an educational institution in which teaching and learning take place [10].

Thus, the academic environment of a higher educational institution can be considered as comprised of the following components:

1. The infrastructural component - the physical environment of educational and scientific activities, equipment and facilities, informational infrastructure and resources.

2. The social component - the educational communities of the students, the faculty and the administration, the relationships between them, the accepted style of communication between them.

3. The axiological component - the values of the given educational institution, its organizational and corporate culture, rules and behavioral patterns of teaching, learning and research activities accepted at this institution.

In our opinion, all the components of an academic environment are interdependent and interconnected, and the changes in one component are likely to lead to the changes in other components.

Digitalization has become one of the major trends of the recent years. It has affected all the spheres of the social life, has introduced numerous changes into all types of activities people are engaged in, has created new opportunities and new formats of interaction, has developed new values and new behavioral patterns [11]. Digitalization has had a great impact on the sphere of education - in order to stay competitive, every educational institution has to provide online educational courses besides traditional "live" ones, use various distant learning technologies while providing even offline courses and communicating with students, develop e-learning materials and distant evaluation and examination formats [12]. All these innovations have led to discussions concerning the perspectives and the consequences of introducing digital instruments and practices into the educational sphere and the ways in which digitalization may affect the academic environment [13].

The analysis of the regulatory documents on the educational sphere issued by the Government of the Russian Federation shows that digitalization in education means mainly changing from physical resources (paper and analog resources) to digital ones [14]. The Digital Educational Environment every educational institution is obliged to develop in accordance with the normative documents is reduced to creating the proper setting for the implementation of educational programmes with the use of e-learning and distant learning technologies which should enable educational institutions to provide educational services for students in any location. So, the described changes in developing the educational environment relate only to the infrastructural component. At present, there are a lot of research papers analyzing methods and techniques and the efficiency of using various e-learning platforms and distant learning technologies [15]. However, possible changes in other components of the academic environment caused by digitalization have not been paid due attention to. Besides, the attitudes of students to changes in the academic environment caused by digitalization and the impact of these changes on the students' academic success have remained beyond the scope of research.

III. METHODS AND MATERIALS

By now, both students and the faculty have experienced a lot of changes in the academic environment caused by digitalization. These changes have affected all the components of the academic environment. The changes in the infrastructural component can manifest themselves in a) transferring all the scientific and research materials into the digital format, establishing e-libraries and providing all the participants of the educational process with access to them; b) transferring all the teaching and learning materials into the digital format - these include lectures, presentations, class and home assignments, tests; c) creating new teaching

materials in the digital format - e-textbooks, e-workbooks, video lectures, quests, computer games; d) creating and introducing LMS into educational practices; e) developing new formats and practices of teaching - giving classes with the help of distant learning technologies, expanding the range of ways of providing information to students - using videos from the Internet as illustration material for lectures, creating assignments on the basis of videos from various video platforms, using elements of AR / VR technologies to create the context for role games and simulation games; f) using AI in the teaching process.

The changes in the social component have led to creating an interactive electronic environment for communication between the administration and the students, between the administration and the faculty, between the faculty and the students. This environment involves creating a corporate website and a corporate mail service of the educational institution, providing each member of the educational community with a corporate mail account upon joining the community, creating an e-platform for holding webinars, discussion forums etc.

The axiological component has also been affected by digitalization. The mobility of the learning process, the availability of electronic "assistants", the opportunities of being provided with immediate prompts and reminders built in the electronic textbooks and workbooks have led to great changes in students' attitudes, strategies and tactics of learning activities [16].

We aim to find out how students respond to changes in the academic environment caused by digitalization. For that we analyze what changes the students have experienced, what their attitudes to these changes are and how they explain their positive or negative responses to those changes. We also attempt to describe how "e-assistants" have changes the students' learning strategies and how this may affect the competences the students are due to attain in the course of their studies.

Research methods

We employed various research methods at the Saint-Petersburg branch of the Financial University under the Government of the Russian Federation and the Department of secondary professional training of the Saint-Petersburg branch of the Financial University under the Government of the Russian Federation (college). In 2022-2024 we used the method of survey to get information about what digital changes in the academic environment the full-time students have already experienced and what their attitudes to these changes are. We also used the method of reflective writing to get information about the reasons the full-time students liked or disliked certain digital practices.

We used the method of observation to get information about the full-time students' learning strategies employed in foreign language classes. The method of the existing data research and the method of observation were used to collect, analyze and classify information about the level of the foreign language linguistic competence of students.

The surveys and observations were held among 1st – 3rd year students majoring in "Business Informatics. IT-technologies for business".

A. Research questions

What digital changes in the academic environment have the students experienced?

How do they feel about these changes?

Why do they like / dislike these changes?

How have the learning strategies of students been modified by digitalization?

How have the target competences the students are due to attain been affected by these changes?

IV. RESULTS

In this part of the paper, first we present the descriptive statistics of the digital changes in the academic environment the students have already experienced. We also present descriptive statistics on the students' attitudes to these changes and the students' explanations on their responses to the digital changes. Second, we present the results of the observations of the learning strategies employed by the students in foreign language classes and the analysis of foreign language linguistic competence attained by the students due to the use of various "e-assistants".

B. Descriptive statistics of the digital changes in the infrastructural component of the academic environment and the students' attitudes to them

The full-time students have already experienced the following digital changes in the infrastructural component: a) e-versions of teaching, learning and research materials; b) video lectures, lectures held with the use of distant learning technologies, e-workbooks, quests, computer games; c) elements of LMS in educational practices; d) watching illustrative videos from the Internet as additional learning materials, doing tasks based on videos from the Internet. The reactions to e-versions of teaching, learning and research materials were 100% positive as the use of e-versions simplifies the access of students to these materials, reduces the financial costs and saves time both for the educational institution and the students for the acquisition of these materials. E-versions of learning and research materials allow different formats of working - they can be accessed from a smartphone or a computer or printed out, which in turn allows taking notes on the margins, translating new words in the text etc. 100% of students respond positively to watching videos from the Internet as illustrative material to the lectures or class or home assignments as it makes the information more interesting, more understandable, more reliable and more topical. Both the students and the teachers note positive aspects of introducing elements of LMS into educational practices - tests or home assignments held with the help of computers are checked immediately, so the students can learn what grades they have got. Quests are considered to be of great interest to students, and students even volunteer to assist teachers in developing quests in certain subjects.

However, other digital innovations don't arise unequivocal positive reactions. Only 25% of full-time students respond positively to video lectures. 45% of full-time students would agree with reservation to "live" lectures being replaced by video lectures or lectures held with the use of distant learning technologies (for example, video lectures in simple or unimportant subjects are acceptable; video lectures must be accompanied with "live" practical classes or seminars etc.). 30% of full-time students said that, all other things being equal, they would prefer "live" lectures to video lectures or lectures held with the use of distant learning technologies in 100% cases. About 90% of full-time students believe that seminars, practical classes and workshops must be held in the "live" format. Among the reasons for the preference of "live" lectures to video lectures or lectures held with the use of distant learning technologies are the following: a) lack of interaction with the teacher during the

video lecture or low level of interaction during lectures held with the use of distant learning technologies which can lead to the inability to ask clarifying questions or make comments; b) perception difficulties - "the speaking head" on the screen looks boring and tiring and prevents the students from working productively; c) inability to have lectures tailored to the needs of the target audience - "the speaking head" on the screen is unable to notice the immediate reaction of students to the lecture caused either by their misunderstanding the lecture, different level of preparation of different groups, tiredness or lack of enthusiasm and take measures; d) lack of organizing and supervisory activities of teachers - students note that they have difficulty organizing their own learning activities, can be easily distracted by multiple reasons, are too relaxed and never concentrate hard as they know that the teacher does not control their activities etc. The preferences and the reasons stated by the students have probably caused the decrease in the quality of educational results noted in educational institutions providing online educational courses in comparison with the educational results of traditional offline courses [17, 18].

C. Descriptive statistics of the digital changes in the social component of the academic environment and the students' attitudes to them

The university has developed an interactive electronic communication system which allows communication between the administration and the students, between the administration and the faculty, between the faculty and the students. In the present academic environment direct communication and electronic interaction combine and complement each other for all the members of the academic community. So far, electronic interaction has not replaced or surpassed direct communication and is seen as supplementary to direct communication by 100% of the respondents. 100% positive aspects of electronic interaction are the possibility of timely informing all the participants of the educational process about unexpected changes in the timetable, about the current events of the academic life etc. For that, students set up official group e-mail accounts to be sent notifications from the administration, home assignments or links to lectures from teachers etc. Besides, students set up groups and chats in various social networks for both academic and informal communication with each other - they inform each other about the news, notifications or home assignments sent to their official group e-mail account to help or alert those who could have missed the news, discuss ways of doing home assignments or preparing for tests or exams, inform the classmates about being absent from classes or being late and sending regards to their teachers, arrange to meet etc. Also, students write to their teachers to ask questions, clarify something etc.

The most frequently mentioned negative aspects of online communication in the students' opinion are low levels of interaction and the lack of formalized rules of online communication with representatives of different social groups. Besides, both the students and the teachers mention a negative consequence of online communication that arose after the period of distant learning that occurred due to the pandemic of coronavirus. Students tend to transfer the behavioral patterns of electronic communication into real life communication, and some of these behavioral patterns can be quite disturbing for the others.

D. Results of the observations of the students' learning strategies employed in foreign language classes and their impact on the formation of the linguistic competence of students

Our long-term observations have shown that STEM students and other students of non-linguistic majors employ the so-called minimax strategies [19] in their studies of a foreign language. It has been noted that for secondary and high school students the so-called achievement learning is the most typical - students aim to get high grades in all subjects regardless of their interest in these subjects with minimal efforts. So, they strive to optimize their learning efforts by using various electronic "assistants" which helps them to save time and achieve the needed results. The learning strategies we observed - a set of methods and techniques that helps the students to gain, acquire, store and use new knowledge [20] and to make the learning process simple, faster, more efficient, more self-centered and more pleasant [21] - are established and developed at school on their own or with the help of their peers. The most popular "e-assistants" for foreign language studies nowadays are translation applications, Generative Artificial Intelligence (GAI), neural networks. Translation applications available at present allow the translation of a whole text rather than the translation of separate words or phrases which was common just a few years ago. GAI and neural networks can retell or summarize any type of text in any format (printed, audio or video text), generate any type of text using simple prompts and, therefore, "assist" in doing traditional assignments such as summarizing the text, answering questions, describing text characters. Besides, these "e-assistants" can expand the given text, improve it by using synonyms, change its style etc.

Various "e-assistants" became the most widely used instrumental component of the students' learning strategies during the Coronavirus isolation period when there was a great lack of teachers' supervising and organizing activities and are very popular nowadays. The existing ones are being modernized and perfected all the time, and new e-products are constantly being launched on the market. In our opinion, delegating doing certain class or home assignments to translation applications or GAI has affected the students' linguistic competence: students have a very narrow vocabulary, do not know parts of speech, do not know the word order in a sentence in a foreign language and cannot translate a simple sentence without translation apps. The entrance tests held at the beginning of the academic year for first year students showed that the number of students with a medium level of linguistic competence decreased by 50% in comparison with the previous years, while the number of students with a low level of linguistic competence doubled. Our further observations of students proved the results of the entrance tests and showed even more problems: the inability of the students to retell the text, to formulate the main idea of the text, to explain answers to the questions using the text etc. We could also observe that in university the students continue using the learning strategies acquired at school and are unwilling to reject them and set up new ones even if they see their inefficiency, which correlates with similar opinions on the use of learning strategies provided by other researchers [21; 22; 23].

V. CONCLUSIONS

Digitalization has affected all the components of the educational environment. However, its impact on the academic success of students can not be considered unequivocally positive, as the changes caused by

digitalization turn out not to be always constructive, favorable, comfortable for all the stakeholders of the educational process. As could be seen, positive reactions to digital innovations are found only in cases where they complement the traditional "live" practices. Cases in which digital practices have substituted "live" practices cause negative reactions and bring negative results.

Certain digital innovations introduced by students into their learning strategies to achieve high grades with minimal efforts happen to hinder their learning progress and the development of the target competences. So, teachers have to timely identify and estimate the effects of students' using popular digital tools and work out ways and means of neutralizing negative consequences. Generally speaking, new teaching techniques and practices should be developed in response to the changing educational environment.

VI. DISCUSSIONS

Digitalization has become part of our lives and its impact on various spheres of life, on any social system and subsystem is going to increase. However, it is important to remember that changes in one element or component of a social system are likely to lead to changes in other components, and the consequences of such changes may not be always positive. So, when alterations are introduced into a system or its component, we need to consider how they relate to or connect with the other systems or components, how all the participants of a certain community or stakeholders in a certain process feel about the changes and what their opinions are.

Digital practices in the educational process are seen as positive when they complement traditional "live" practices. This paradoxically shows the role of a "live" teacher in the educational and academic process. The students express the need a) to interact with their teachers on all the stages of the learning process despite the abundance of the e-resources available to them, and b) to be supervised by their teachers in organizing and carrying out their learning and research activities. The role of the teacher is also emphasized by the fact that it is the teacher who detects and determines current problems that may arise in students' learning and research activities and strategies and who is to prevent possible negative effects of using certain innovations and risks of the quality of the educational results being decreased by developing new teaching strategies and practices.

To provide for the high quality of the educational process and to increase its efficiency in the era of digitalization, it is necessary to carry out complex psychological and pedagogical research concerning such issues as the balance of traditional "live" and digital formats of teaching, the optimal ratio of direct and electronic interaction between all the stakeholders of the academic process, developing methods of control of academic achievements and creating means of provision of quality of the educational result in an electronic teaching and learning environment. It is also necessary to reconsider the role of the teacher in the educational process, the competences they need to possess to ensure the proper development of the students' cognitive and professional competences in the digital era and the standards of professional training future teachers need to get.

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Development of an AI-Consultant for a Design Engineer Using a Neural Network and a Dynamo Script

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Abstract – This article describes to the creation of an advisory tool for design engineers based on modern artificial intelligence technologies. The basis of the tool is a neural network trained on a vast array of data, including modern rules and regulations and data from technical documentation. The system interacts with users through a special interface on the Dynamo platform, which is integrated directly into the workspace of BIM solutions such as Autodesk Revit.

Keywords – information modeling, artificial intelligence, visual programming, design.

I. INTRODUCTION

In the ever-evolving construction industry and architecture, efficiency is a key factor. To successfully complete projects, you need to complete everything in a short time frame with the least number of errors. In order to cope with the set of tasks on time and efficiently, construction organizations widely use automation at all stages. In addition, currently the most promising area is the use of artificial intelligence (AI), which has already proven its effectiveness in various fields, including medicine, finance and manufacturing. Currently, there is an active interest in the introduction of AI technologies in the construction industry, especially in the context of building information modeling (BIM) [1, 2].

The design of industrial buildings is a complex and multi-step process that requires consideration of many factors such as safety, functionality, economic feasibility and compliance with regulatory requirements. Modern tools such as the Revit program significantly simplify this process due to the possibilities of building information modeling.

Natural language processing models (ChatGPT, GigaChat, Neuro in Yandex) help process texts, documents, and other information presented in natural language. In construction, these models can be a good tool for solving the following tasks (Figure 1):

- search and extract data from technical documentation;
- modification or creation of information model elements,
- search for items by description;
- search for project information on the Internet;
- communication with project management systems using voice commands;
- create reports and presentation materials based on model data.

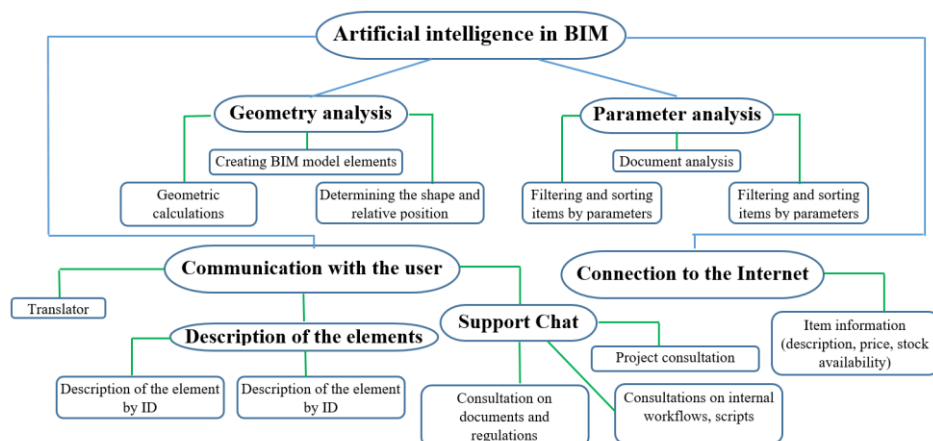


Fig. 1. Directions of artificial intelligence development in BIM

These methods of artificial intelligence significantly expand the possibilities of information modeling of construction sites, allowing to improve the quality of projects, reduce costs and minimize risks [3, 4]. The use of these technologies requires the integration of specialized software platforms and tools, as well as the training of qualified specialists who can effectively use the potential of artificial intelligence in their work.

It is quite that the use of artificial intelligence in building information modeling programs (in particular Revit) makes it possible to bring automation of all processes to a higher level. At the same time, the number of errors caused by the human factor will be significantly reduced, and the time required for project development and approval will be reduced. Figure 2 shows the simplest way to use artificial

intelligence when working with an information model – without integration into a BIM program.

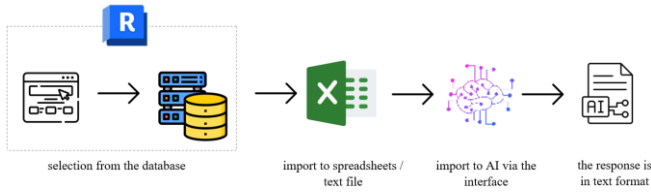


Fig. 2. Using artificial intelligence without integration into Revit.

A more complex method (in terms of the qualifications of specialists) – artificial intelligence is integrated into a BIM program is shown in Figure 3.

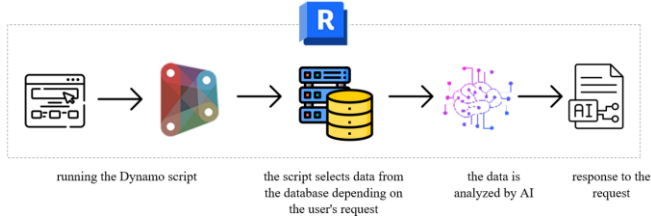


Fig. 3. Integration of artificial intelligence into Revit.

When considering two approaches to using AI in conjunction with an information modeling program, it becomes obvious that integrating AI into the software package will help reduce the number of errors and reduce the time of routine operations of the designer.

Currently, there are a number of tools for Revit that realize the benefits of AI. For example, the Veras extension-based on the building information model renders with textures, shadows, and styles. The Wise BIM extension Wise BIM turns a two-dimensional drawing into a three-dimensional model in Revit, but without parameters and with a simplified geometry. The Revit Wizard extension-ChatGPT allows you to get help information on Revit, explains how functions work, but is not integrated into Revit.

II. INTEGRATION OF AI INTO REVIT TO RESPOND TO DESIGNER'S REQUESTS

An important task during the preparation of the project is to obtain background information on the full functionality of Revit. Insufficient awareness of the program's capabilities and questions about rarely used or specific functions lead to the need to seek help from BIM specialists. All this not only slows down the design process, but also creates additional organizational and time costs.

To integrate artificial intelligence into Revit, it is convenient to use the Dynamo visual programming system – it does not require programming skills. Scripts that consist of nodes (blocks) are used to automate and build queries [5]. Nodes contain library functions that process elements and other information. The advantage of using visual programming is a visual description of the relationship between the elements by creating logical circuits [6].

To use Dynamo scripts in building information modeling (BIM) programs, you need to configure the work environment. Let's look at the main stages of setting up the environment.

1. Install the necessary applications. At this stage, you need to install the Dynamo Studio extension package and Python scripting libraries. These components provide the

creation, integration, and launch of scripts in the information model.

2. Creating Dynamo scripts. At this stage, scripts are being developed that ensure the transfer of input data from the BIM model to the neural network and receiving recommendations back to Revit.

3. Integration of scripts with the Revit interface. At this stage, you can use the Revit API and Dynamo visualization tools to create a user-friendly interface that allows you to easily run the necessary queries and view the responses received directly inside the BIM environment.

4. Testing the settings. At this stage, internal testing of the tool is performed among the developers of the project organization to collect comments, identify errors and improve performance.

5. Regular data updates. During use, it is necessary to update neural network versions and scripts as new versions become available and regulatory documentation changes.

III. METHODOLOGY

This article proposes the creation of an AI consultant for a design engineer based on the integration of artificial intelligence, in particular the ChatGPT neural network, into the Revit building information modeling program via the Dynamo script. This approach helps to increase the productivity of a design engineer due to the ability to instantly receive advice and tips on various aspects of design right in the process of working on a project. There is no need to constantly switch between multiple applications and information sources, which increases the speed of work and reduces specialist fatigue. In addition, the use of an AI consultant facilitates the exchange of information between project team members, and the regular provision of up-to-date background information and training materials supports the professional competencies of designers.

IV. CREATING A QUERY SCRIPT FOR A NEURAL NETWORK

The authors propose an option for developing an advisory tool that integrates the capabilities of artificial intelligence (AI) [7], in particular the ChatGPT neural network, into the Revit building information modeling program via the Dynamo script (Fig. 4). This tool allows users to ask questions about working in Revit and receive answers in real time, providing convenient access to information and improving the productivity of designers.

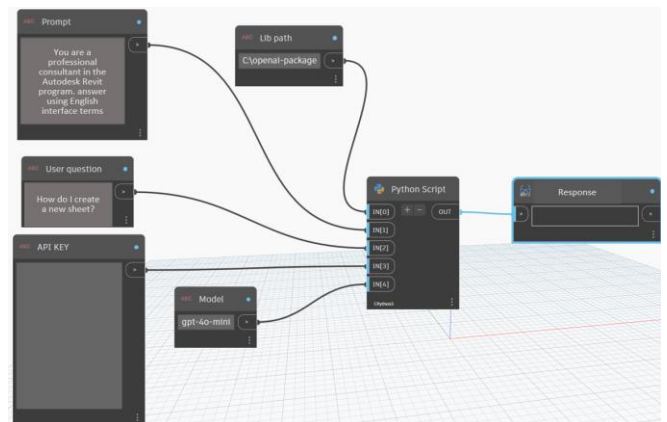


Fig. 4. A script in the Dynamo environment.

The algorithm of the developed script is represented by the following main stages (Figs. 5, 6):

Step 1 – Add paths and import libraries.

Step 2 – Data is transferred from Dynamo.

Step 3 – The API is configured for OpenAI.

Step 4 – The headers are configured.

Step 5 – Messages are generated for the neural network model.

Step 6 – The data is being prepared for the request.

Step 7 – The POST request is executed directly.

Step 8 – The result (response) is extracted from ChatGPT.

Step 9 – Tokens are extracted.

Step 10 – the result (the received response) is returned to Dynamo.

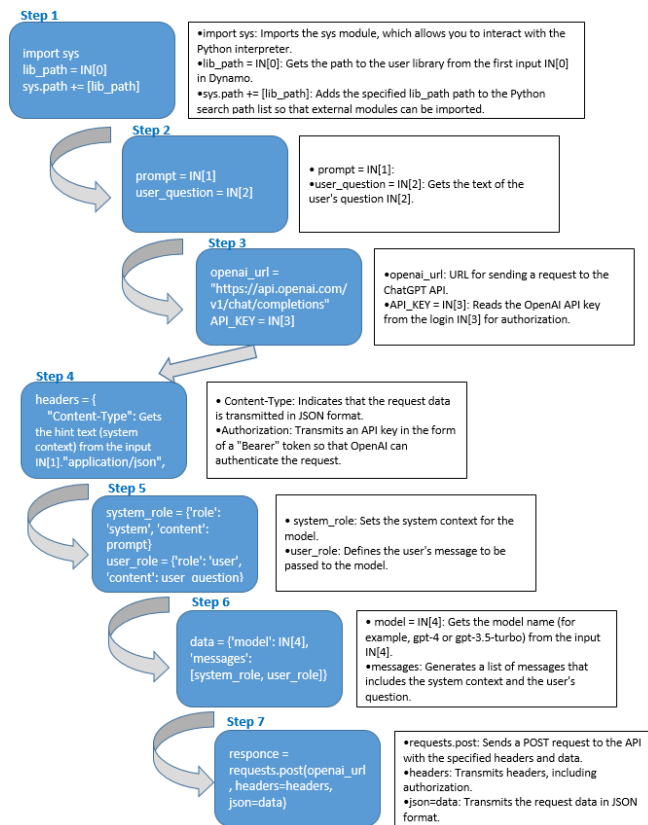


Fig. 5. Preparing a request to the neural network

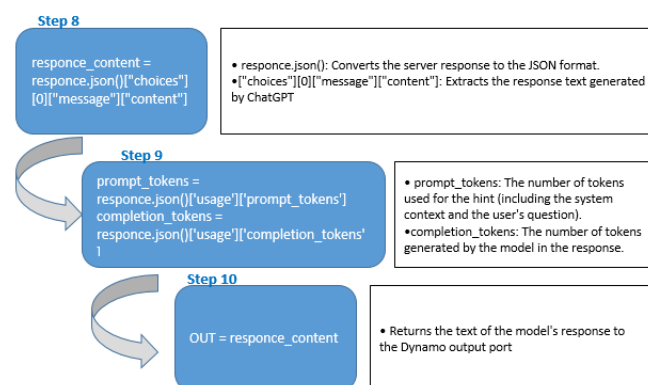


Fig. 6. Getting a response from a neural network in Dynamo

An example of the program code for the script implementation:

```
import sys
lib_path = IN[0]
sys.path += [lib_path]
import requests
prompt = IN[1]
user_question = IN[2]
openai_url = "https://api.openai.com/v1/chat/completions"
API_KEY = IN[3]
headers = {"Content Type": "application/json", "Authorization": "Media" + API_KEY}
system_role = {"role": "system", "content": prompt}
user_role = {"role": "user", "content": user_question}
data = {"model": IN[4], "messages": [system_role, user_role]}
response = requests.post(openai_url, headers=headers, json=data)
response_content = response.json()[0]["message"]["content"]
prompt_tokens = response.json()[0]["usage"]["prompt_tokens"]
completion_tokens = response.json()[0]["usage"]["completion_tokens"]
OUT = response_content
```

The following can be identified as promising areas for the integration and development of AI in information modeling:

- Automatic creation and updating of models: Artificial intelligence can be used to automatically generate models based on specified parameters and requirements. This includes the creation of basic building frames, the placement of basic structural elements, as well as the addition of engineering systems. As noted above, prototypes of programs with AI modules have already been developed that turn a two-dimensional drawing into a three-dimensional model with simplified geometry and render based on the building information model. This approach significantly reduces the time required for project development and approval.
- Strength calculation and optimization of the structure: When designing any building structure, the most important stage is the selection of materials and calculation for various loads and impacts. Currently, special calculation software systems are most widely used, which require high qualifications and attention from an engineer. Using AI capabilities, you can analyze a large number of existing projects and identify patterns in materials and loads. Based on the obtained patterns, several project options can be considered and the optimal one can be selected according to the specified parameters. This approach will help to increase the reliability of construction projects.
- Sharing AI with databases and ERP systems: In the process, organizations often have to refer to regulatory documents and standards. Creating modules containing neural networks for searching and displaying the necessary information is one of the urgent tasks. The use of AI consultants will be able to ensure that the information is up-to-date and facilitate the process of project coordination with stakeholders.
- Creation of virtual tours and interactive presentations: using AI to generate photorealistic images and videos allows you to create virtual tours of the future building, which is useful for demonstrating the project to customers and investors. Interactive presentations help to better understand the specifics of the project and make informed decisions.

V. CONCLUSIONS

As a result of the research, the concept of an intelligent assistant has been developed based on the integration of the ChatGPT neural network with the Revit program through Dynamo scripts. The resulting system is a simple but

effective decision support tool that increases the productivity of design engineers.

Very often, a lot of time is spent searching for background information on the functionality of the program or the necessary information from regulatory documents. Designers have to contact their colleagues and wait for a response from them. The developed algorithm for integrating ChatGPT with the Revit program through Dynamo allows you to promptly provide qualified information support to engineers at all stages of design.

Intelligent assistants for design engineers are currently being actively developed not only based on existing chat-GPT and other language models, but also based on Retrieval-Augmented Generation (RAG) technology. RAG technology requires more development and debugging time than the algorithm proposed in this paper. The described algorithm can be improved by adding to it the ability to search for regulatory documents on the project.

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Development of a Digital Twin for Assembly and Packaging Processes Using the R-Pro Modelling Environment

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Abstract—The article discusses the relevance of the application of digital twins in modern manufacturing to effectively manage work processes and improve production efficiency. Various tasks that can be solved using digital twins are analyzed. The modelling of the sequence of operations in the development of a digital twin within the technological process of skateboard assembly and packaging using R-Pro ‘Rational Production’ software is considered.

Keywords— *Digital twin, Simulation modeling, R-Pro, Robotic system, Production automation*

I. INTRODUCTION

The modern world is undergoing a digital transformation associated with large-scale processes of changes in the functioning of individual companies and entire industries, based on the rapid development of end-to-end technologies, which most often include artificial intelligence and machine learning, the Internet of Things and big data, distributed ledger and blockchain technologies, robotics and quantum technologies, virtual and augmented reality, predictive analytics, and digital twins.

Digital twins allow to preemptively avoid accidents and technical failures in production by pre-testing the developed model in a digital environment [1-4].

The robotics complex of the laboratory of the Intelligent Control and Automation Systems department is actively developing digital twins. A digital twin of an enterprise is a model of the enterprise created in a virtual environment. For the majority of production tasks, the digital twin allows to reproduce technological processes and operations with high accuracy.

When using a digital twin, the researcher can conduct hypothesis testing based on the parameters and capabilities built into the product according to the original specifications. It is important to note that the digital twin is not limited to tracking the current situation, but is designed to anticipate future project scenarios [5-8].

Creating a digital twin of an industrial object is a complex and multi-level process. Experts distinguish four main stages of development, listed below.

Survey: a thorough study of regulatory documentation, technical charts, and interviews with enterprise experts. This stage allows you to gather a complete picture of the enterprise, taking into account even non-digitised processes that are stored in the ‘heads’ of employees.

Development: creating a virtual infrastructure and recreating the operations of the enterprise using flowcharts and programme code. Development is done in a specialised program such as R-Pro.

Validation: testing the model on historical data and then eliminating errors and inaccuracies to achieve minimal discrepancies with actual results.

Exploitation: using the developed digital twin to solve enterprise problems.

The key role of using digital twins can be noted in the construction of various technological processes, as most of the technological processes are designed initially at the modelling stage, where digital twins are applicable [9-11].

Modern production requires highly qualified personnel, which are trained at universities. The Moscow Technical University of Communications and Informatics at the Department of Intelligent Systems in Control and Automation has opened a robotics centre, within the framework of which work with robotic complexes is actively carried out, teachers, graduate and postgraduate students are engaged in scientific research [12-14]. The results of their activities are published in articles that consider control systems of robotic complexes with the help of intellectual technologies, including computer vision and neural network modelling [15-17].

II. DEVELOPMENT OF A DIGITAL TWIN IN R-PRO

The article describes the solution of the problem of creating a model of a digital twin of the technological process of assembly and packaging of some production piece products and its storage, using the R-Pro programme.

R-Pro Digital ‘Rational Production’ software platform for creating digital twins, simulation modelling and offline programming of robots and other industrial equipment. This software allows you to create digital twins of production taking into account all technological parameters and behaviour of real objects in the industry or the plant as a whole.

The software allows to optimise technological processes in a virtual environment without stopping production, and to make changes much faster and safer than when experimenting on real objects.

The developed model consists of several stages: creation of a model of an automated warehouse with skateboard blanks based on Cartesian coordinates in the working environment space, logistics of movement from shelves to

conveyors with the help of mobile robots, construction of an automated line of conveyors and industrial robots, assembly of final products, shipment to the warehouse.

When creating a digital twin of the skateboard assembly and packaging process, the first step is to create an automated model of the warehouse where the blanks for the finished product, i.e. components for the skateboard, will be stored.

Using the catalogue panel of the R-Pro program, you can build a warehouse layout using the following components: warehouse shelf, mobile robot, conveyor, manual workstation, transport controller, human, travel zones. Fig. 1 shows the warehouse layout.

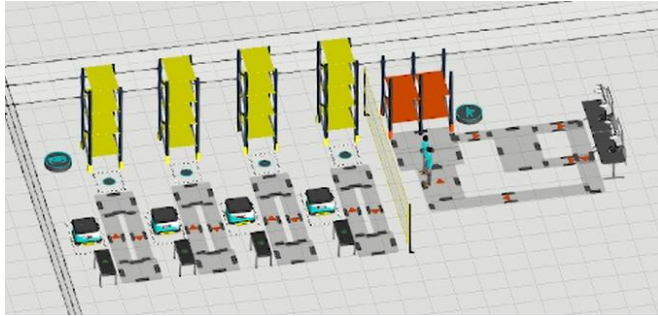


Fig. 1. Model of an automated warehouse.

The first step is adding stock shelves from the component catalogue by moving the finished object models into the workspace window. Next, a process node is placed near each stock shelf to generate the skateboard components on the shelves. Fig. 2 shows the placement of the process node for a warehouse shelf.

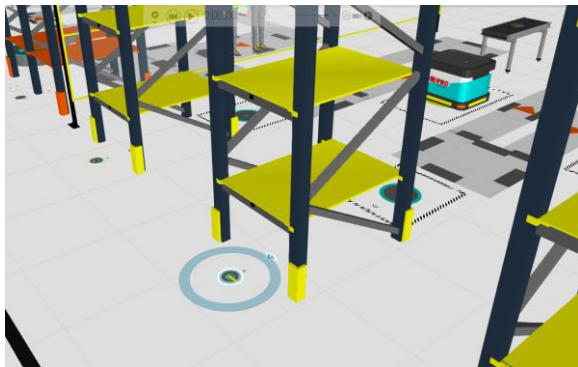


Fig. 2. Placement of the process node.

A process node is part of the creation of technological processes. By creating many process nodes and correctly linking them together in the required sequence, a whole technological process is created. For a process node you can set commands to create objects, move objects from one node to another, set various cycles and logistic functions to build the process model.

To make each process node generate an object, in the 'Process' tab, through the operation editor, open a window for adding commands to the process node. The nodes specify the creation of necessary parts, such as assemblies with box and parts, and further command to send to the shelves. Fig. 3 shows the commands of the process node.

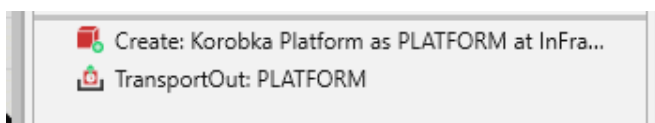


Fig. 3. Process node commands.

In order for these assemblies to be created, they must be created in the parts tab. Figure 4 shows the assembly being created.

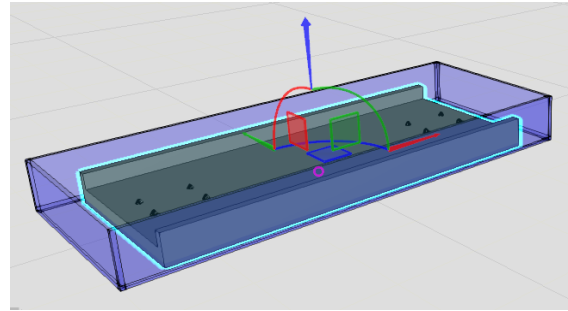


Fig. 4. View of box assembly with stand.

Each step shows the sequence of actions in the assembly, for example, step 1 the box itself, step 2 added the skateboard deck.

A process similar to a node is created on the shelves, but not for dispatch, but for storing parts in itself. Once the processes are created, they are connected to each other for logistics work.

The shelf is created, the process of parts delivery to the shelves is configured, the next action is to organise the delivery of parts from the shelves to the conveyors, for this purpose the conveyor itself is placed with a built-in node in which the logic of accepting and sending parts is configured, as shown in Fig. 5.

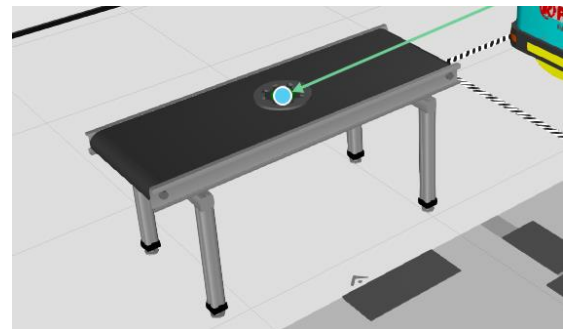


Fig. 5. Conveyor with integrated assembly.

The command window of the process node specifies the acceptance of parts from a variable that is involved in previous processes on the shelves.

The logistics from the shelves to the conveyors is done by mobile robots, for their operation a transport controller and the robots themselves are installed in the model. Fig. 6 shows the mobile robot and its controller.

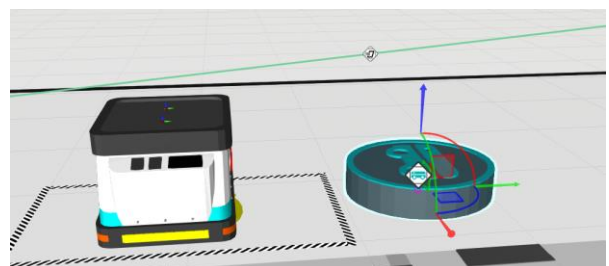


Fig. 6. Mobile robot and controller.

To configure robots via the controller, you need to open the controller interface. In the interface, configure the resources, which are the available robots. Routes on which

the robots will move and parking places. Fig. 7 shows the result of configuring the robots via the controller interface.

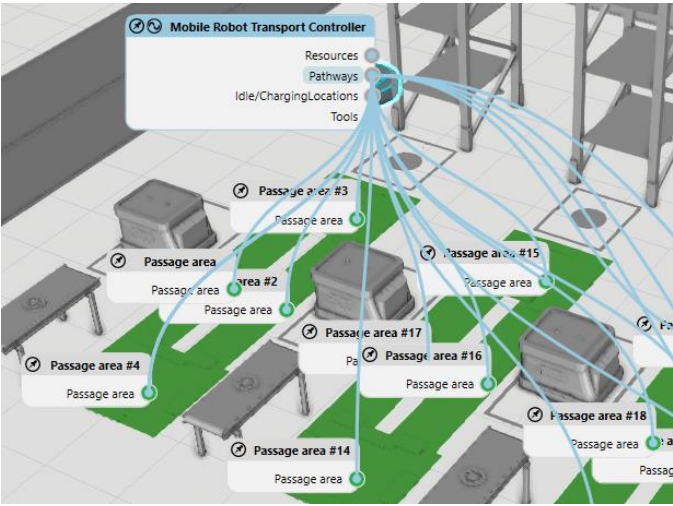


Fig. 7. Customisation of robots via the controllers' interface.

In this way it is done for all the robots that are in the process, each shelf has a place to wait for the robot, and a place where the robot will pass, in the properties of these zones can be specified in which direction they can move, thus preventing the movement of several robots in the same direction, and also to delimit the lanes. Fig. 8 shows the working area of mobile robots.

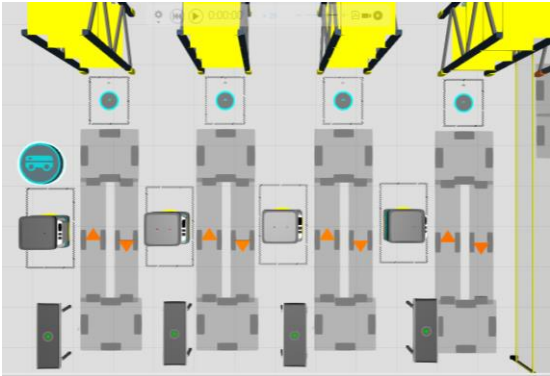


Fig. 8. Direction of movement of the robots.

After the robots have been configured, they can be used to move parts, for this purpose the configured mobile robot controller is specified when linking the processes.



Fig. 9. A model of moving parts using humans and robots to assemble a skateboard.

For the realisation of moving boxes with parts by people, the process of creation is completely similar, instead of robots a human model is used, as well as a controller responsible for the configuration of human models.

The final model, presented in Fig. 9, in simulation shows the result of moving parts in boxes for skateboard assembly with the help of people and robots, the zones of work of which are delimited and configured in advance.

To assemble the skateboard from parts from the warehouse, a process is designed in the second stage, where an automated line of conveyors and industrial robots is built. In addition, a person is present at the assembly stage who is responsible for preparing the stand with bolts. Fig. 10 shows the layout for the skateboard assembly.

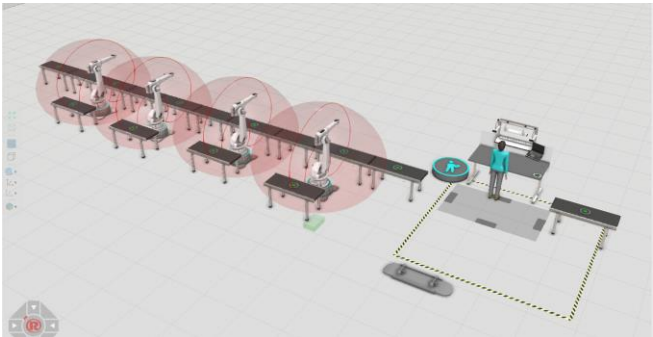


Fig. 10. Skateboard assembly model.

Beforehand we create an 'assembly' with the parts that will be used during the whole assembly process. The result of the 'assembly' is shown in Fig. 11.

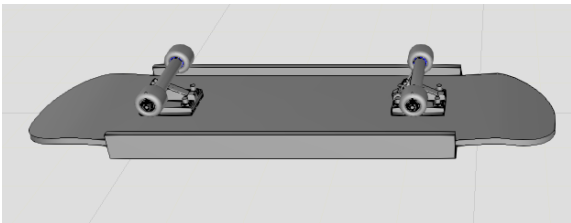


Fig. 11. Created skateboard assembly.

To visualise the placement of the bolts on the stand, the workstation process units are programmed. This process consists of 3 parts: removing parts from boxes, placing all 8 bolts on the stand, transferring the result to the conveyor. The sequence of actions in the nodes is shown in Fig. 12.

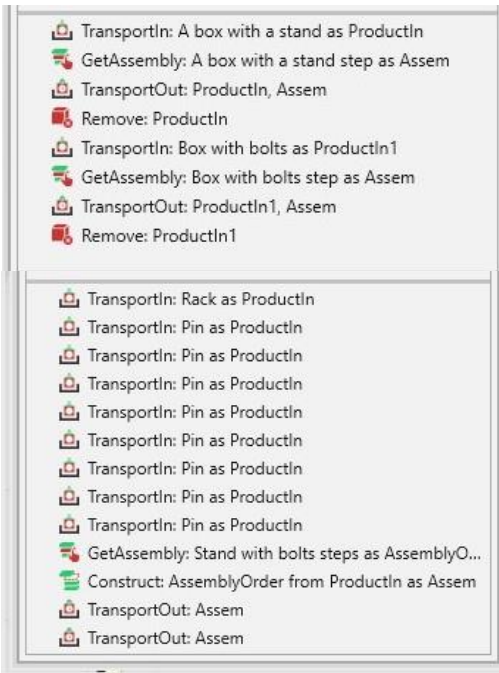


Fig. 12. Preparation process of the bolted stand.

As the part moves along the conveyor, 4 robot arms sequentially perform assembly. Fig. 13 shows the sequence of processes.

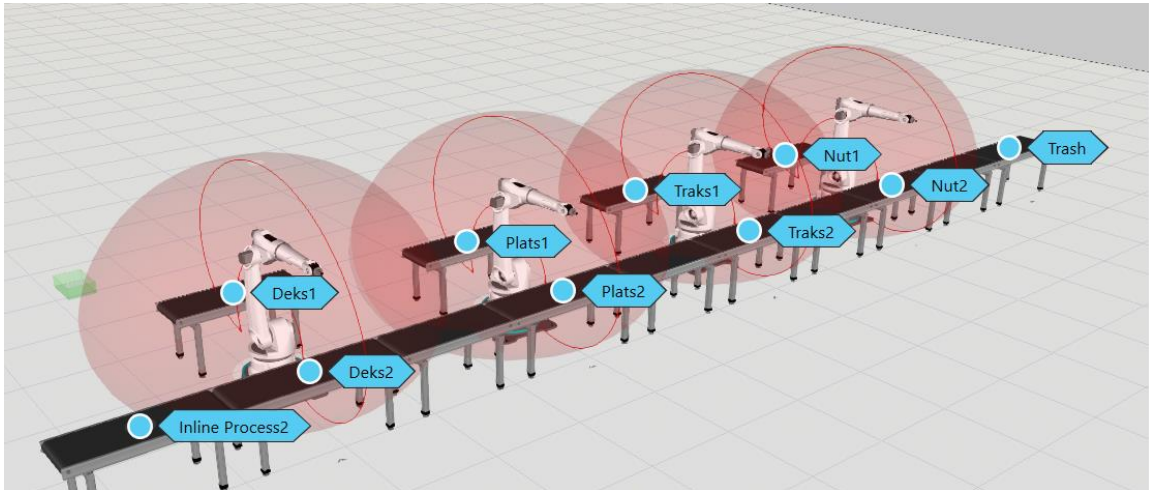


Fig. 13. Sequence of assembly processes with manipulators.

The product arrives on the main conveyor to the working area of the robot arm. The robot arm takes a new part from the box and places it on the product according to the assembly diagram. Fig. 14 shows the commands on the assembly process nodes.

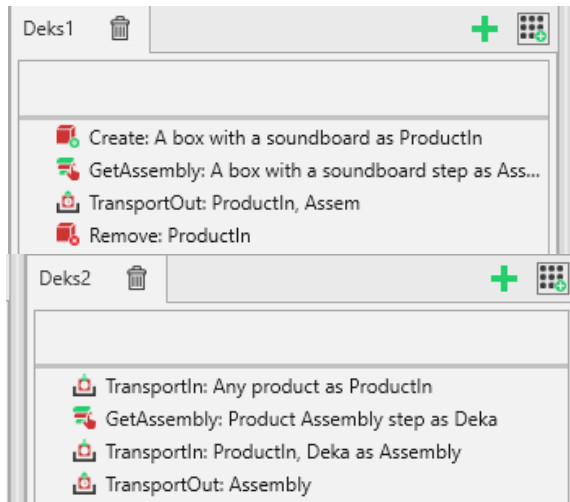


Fig. 14. Commands on process nodes for skateboard assembly.

When the work is finished in the first working area of the first manipulator, the conveyor moves the workpiece to the next working area of the second manipulator. And so on until all the parts are installed.

The result of all processes is the finished product. Fig. 15 shows the result of skateboard assembly.

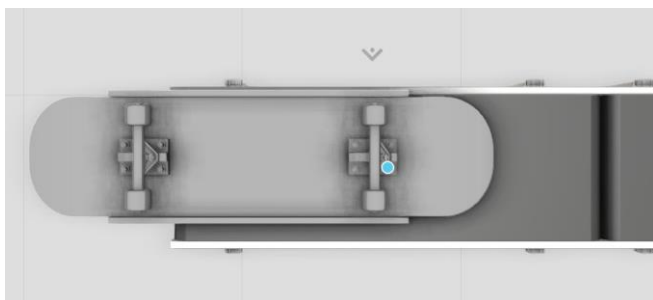


Fig. 15. Skateboard assembly result.

At the third stage, a model of the process of packing finished products into boxes and storing the products in a warehouse is created.

At this stage two robots-manipulators are used, a conveyor on which the finished product arrives, a conveyor on which skateboard boxes are moved, as well as a conveyor with pallets on which the finished product is assembled and two crane-stackers for stacking boxes on the warehouse shelves.

The layout of the whole stage of packing a skateboard into a box and moving the goods to the warehouse is shown in Fig. 16.



Fig. 16. Planning of the robotised area for packaging of finished products.

In order for the robot arm to pack the product into a box, it is necessary to create the corresponding assembly, as shown in Fig. 17.

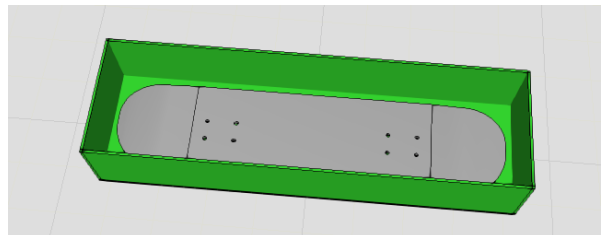


Fig. 17. Assembling with a finished skateboard.

The process where the robot picks up the finished product and packs it into a box is shown in Fig. 18.

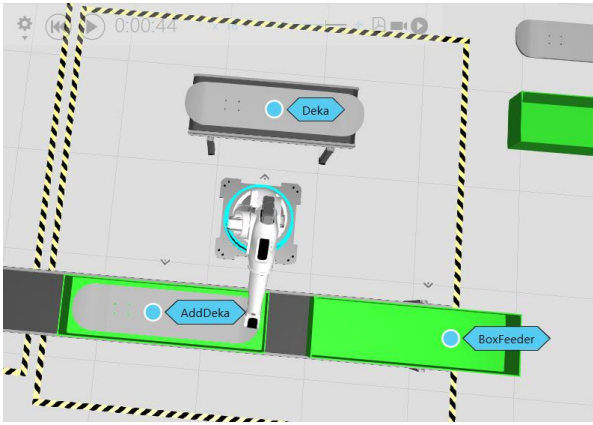


Fig. 18. Packing a skateboard into a box with a manipulator.

The box is transported along the conveyor to the second manipulator. Its task is to put 4 boxes on a pallet. To do this, it is necessary to create an assembly with a pallet, as shown in Fig. 19.

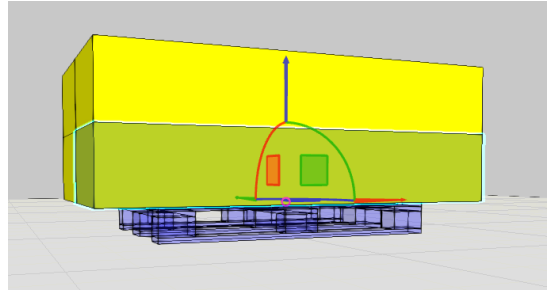


Fig. 19. Assembly with boxes and pallet.

To move boxes to pallets, program the process nodes BoxSort and PalletSort as shown in Fig. 20.

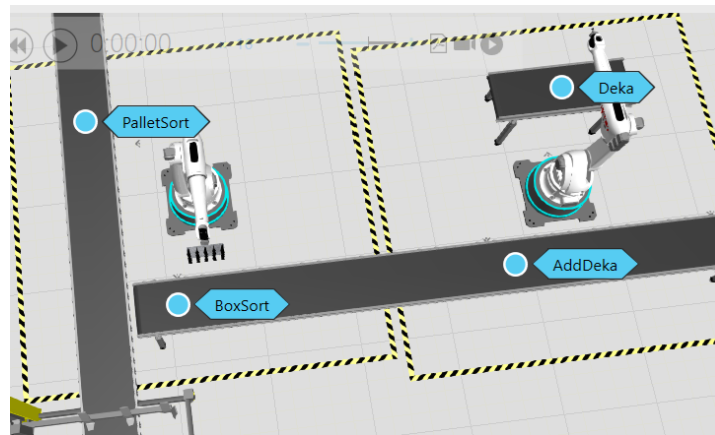


Fig. 20. Programming of process units for moving the box onto the pallet.

After the pallet arrives in the storage area, two stacker cranes start moving the boxes to the storage shelves. Fig. 21

shows the process of stacking boxes with the finished product.

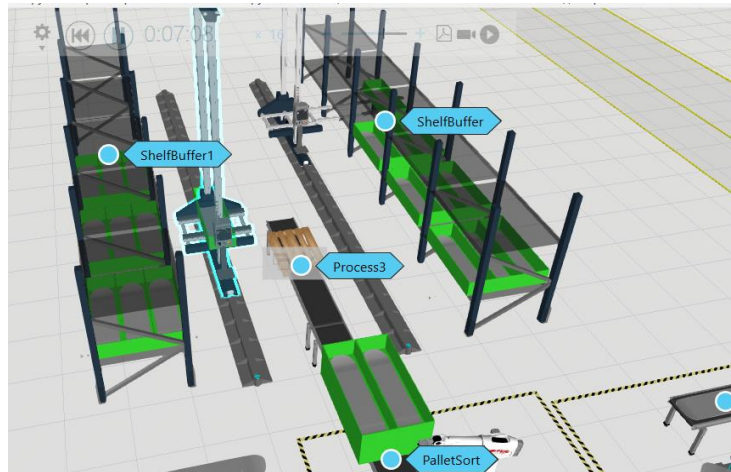


Fig. 21. The process of stacking boxes with a stacker crane.

As a result, the warehouse is filled with finished goods as shown in Fig. 22.

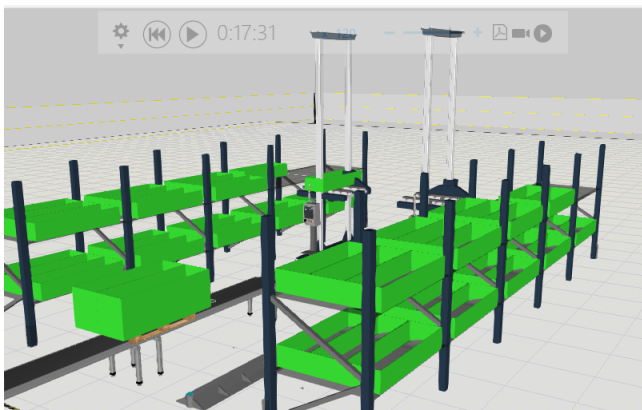


Fig. 22. Result of stacking boxes in the warehouse.

III. CONCLUSIONS

The article describes the process of development of a digital twin model for the technological process of assembly and packaging of a technical object (skateboard). All the main stages of development are given, including the design of working space, including the set of necessary equipment, design and selection of elements for the skateboard, its assembly, transportation by conveyors, packing into a box and its transfer to a pallet with the help of a robot-manipulator.

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Development of Unmanned Research Vehicles with Control System Based on Artificial Intelligence

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Abstract— The goal of research is the research vehicles development. The object of research is the control system. The control is performed without pilot. The applied methods are the artificial intelligence methods and game theory. The artificial intelligence methods are the artificial neuron networks and fuzzy logic. The game theory is applied for strategy choice. The results of investigations are the structural schemas of the control systems.

Keywords— *research vehicles, artificial intelligence methods, game theory, artificial neuron networks, fuzzy logic.*

I. INTRODUCTION

The goal of this article is the development of unmanned research vehicles. The automatic research vehicles are needed for use in dangerous for a man's life conditions.

The object of research is the control system of the automatic research vehicles. The control is performed without pilot.

The tasks to be solved are:

- the design of the structural schema of the control system
- the choice of means for the control system realization.

The applied methods are the artificial intelligence methods and game theory. The artificial intelligence methods are the artificial neuron networks and fuzzy logic. The game theory is applied for strategy choice.

II. DEVELOPMENT OF UNMANNED RESEARCH VEHICLES

Adaptive robotic systems were adopted as the basis for the creation of control systems for unmanned research vehicles [1,2,3].

Adaptive robotic systems are the means of automating of assembly operations in mechanical engineering.

Distinctive features of adaptive robotic systems are adaptability and flexibility. Adaptability is the ability to automatically adapt to the unpredictable changes in the assembly area. Flexibility is the ability of quickly change to assemble the new products.

These important properties are provided mainly by replacing the usual firmware systems fundamentally new multiprocessor adaptive systems called as the adaptive robotic complexes.

Adaptive assembly complexes consist of several manipulative robots with the adaptive and flexible group control system. The robots are entrusted with the main technological operations and some auxiliary operations for the manipulation of details and maintenance of equipment.

Adaptive assembly systems include some subsystems. They include information system, sensors, control units, communication system (with human-machine interface), adaptive system of group control of robots and technological equipment (Fig.1)[1].

The microprocessor and microcontroller systems are the technical basis for the implementation of flexible and adaptive automated control systems. The composition and configuration of the firmware is determined by the set of tasks and functions to be solved.

The control system has a hierarchical structure that includes the following levels:

- the executive (tactical) level;
- the strategic (coordinating) level.

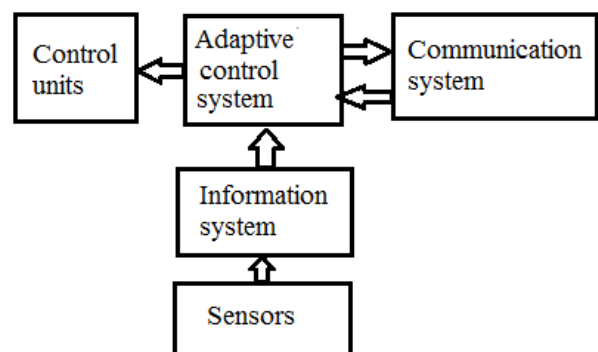


Fig. 1. The structural schema of adaptive robotic system

At the executive level the control system solves the tasks of adaptive control of individual devices, robots and machines. At the coordination level the control system solves the tasks of group adaptive control, coordination and synchronization of individual control systems. The control functions in all levels perform in real time mode. It is advisable to parallelize computing processes by allocating individual data processing functions and algorithms in the set of modules. Modular hierarchical structures are used to parallelize computations in adaptive control systems.

The development of requirements for the hardware and software complex of intelligent control systems in mechanical engineering was described in articles [2,3]. The

structural schema of the control system based on artificial intelligence is presented in Fig.2

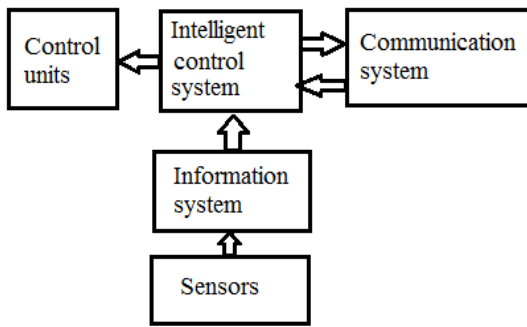


Fig. 2. The structural schema of the control system based on artificial intelligence

The designed intelligent control system include fuzzy logic model [4] and trained neural networks [5-6]. The switcher neural networks were described in patent[5-6]. Switcher neural networks are designed from the trained fragments. The trained fragments are interconnected with the switchers.

The fragments of the neuron networks are trained with the training set. The results of training are stored in the switcher random access memory. The results of training can be exported, imported, duplicated and copied. So the cost of the neuron network design and training can be reduced.

The fuzzy logic model (Fig. 3) was applied for the strategy choice. The fuzzy logic model was designed as the switcher neural network, see Fig.4.

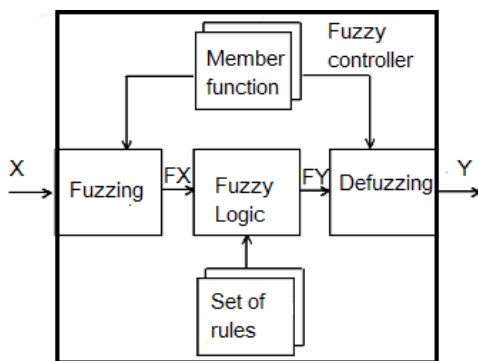


Fig. 3. The fuzzy logic model for the strategy choice

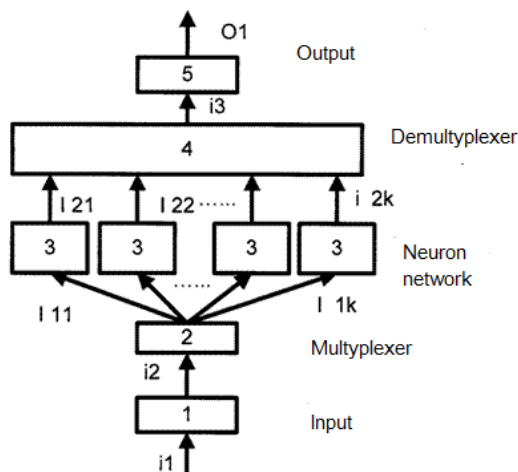


Fig. 4. The switcher neural network for fuzzy logic model

The fuzzy logic model (fig.4) uses the switcher neuron network, multiplexor and the demultiplexor. The multiplexor and the demultiplexor can be realized as the additional switchers.

The switcher networks are designed as the set of the firmware unified modules. The unified module structure is presented in Fig.5.

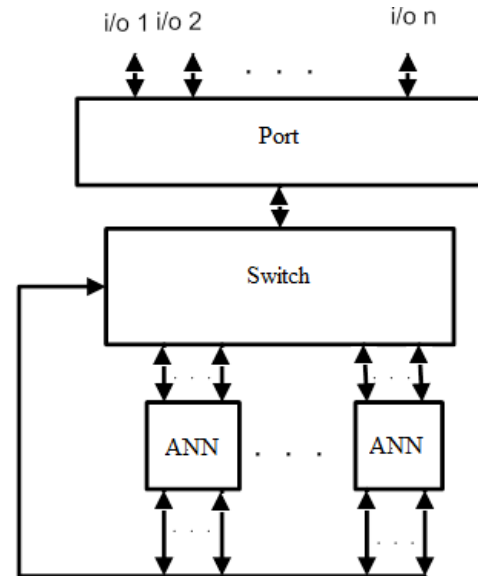


Fig. 5. The module structure, ANN-artificial neural network

The set and the number of the fuzzy rules can change, increase or decrease. The switchers allow to retrain some fragments without the need of the entire neural network redesign.

The strategy of control is described in the set of the fuzzy rules. The fuzzy rules and the membership functions can be realized in the firmware neuron network modules.

The proposed fuzzy logic model can be applied to the entire control system and to any subsystem, part and element. The firmware unified modules are interconnected by the network, see Fig.6.

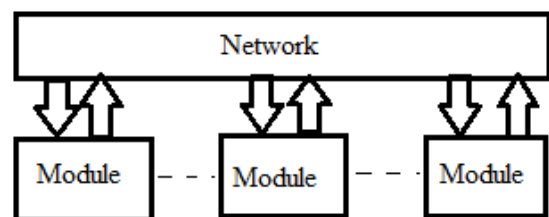


Fig. 6. The interconnection of the unified modules

III. THE FUZZY LOGIC MODEL FOR STRATEGY CHOICE

The fuzzy logic model was applied to the strategy choice.

The input information X is data set from sensors. X is put into the phasifier. The phasifier converts X into the fuzzy linguistic variable FX. $FX \in \{\text{Low, Normal, High}\}$.

The set of fuzzy rules was applied to the FX. The set of rules is represented in the form of conditions

" If FX Then FY"

The examples of the sets of the input and corresponding output fuzzy linguistic variables are presented in Fig. 7,8

$FY \in \{\text{move forward, stop, move backward}\}$

- 1) If Low Then move forward.
- 2) If Normal Then stop.
- 3) 3.If High then move backward.

The linguistic variable FY is put into the defasifier. The defasifier converts the linguistic variable FY into the control command Y.

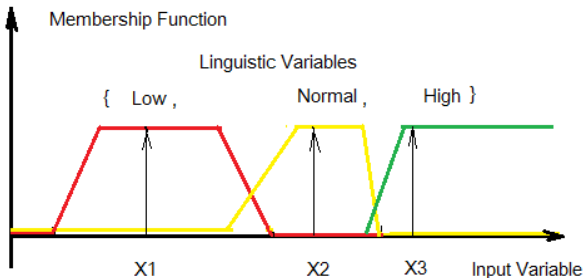


Fig. 7. Membership function of input linguistic variable FX

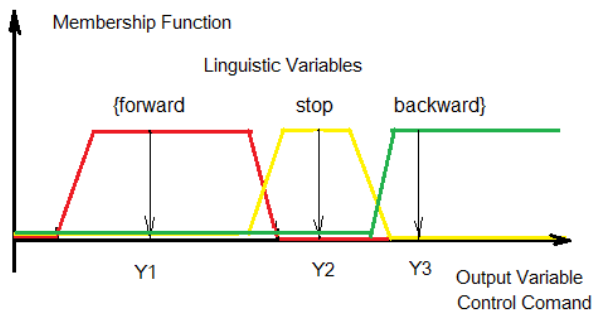


Fig. 8. Membership function of output linguistic variable FY

The multilayer computing system is proposed for fuzzy model design[7].

The fuzzy logic model performs the pilot function in unmanned research vehicles. The fuzzy logic model chooses the strategy and estimates the result of the control.

IV. CONCLUSION

The objects of the research are the control systems for unmanned research vehicles. The control systems get the control commands from operator and input data signals from sensors. The output signals of the automated control system put into control units.

The unmanned research vehicles can be used in aviation and space, in transport systems and in underwater researches, etc.

The results obtained can be useful when combined with the results of work [8], as well as works [9].

Construction of China's first unmanned submarine of the new type "Blue Whale" began in June 2024.

The control system of unmanned submarine is implemented on the basis of artificial intelligence. The control system of unmanned submarine increases efficiency in difficult ocean conditions compared to manual control. The unmanned submarine is equipped with water quality sensors, underwater cameras and bio-acoustic detectors to monitor the situation in the ocean in real time mode.

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Development of Environment Monitoring with Control System Based on Artificial Intelligence

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Abstract— The goal of research is the environment monitoring development. The object of research is the control system. The applied methods are the artificial intelligence methods. The artificial intelligence methods are the artificial neuron networks and fuzzy logic. The results of investigations are the structural schemas of the environment monitoring systems.

Keywords— *environment monitoring, artificial intelligence methods, artificial neuron networks, fuzzy logic.*

I. INTRODUCTION

The goal of research is the environment monitoring system development. The object of research is the control system for environment monitoring. The applied methods are the artificial intelligence methods. The artificial intelligence methods are the artificial neuron networks and fuzzy logic. The tasks of investigations are:

- the structural schemas design for environment monitoring systems,
- the extended function abilities for environment state estimation and prediction,
- the choice of the technical means for the environment monitoring system design.

The article considers the use of artificial intelligence technologies for environmental monitoring and environmental assessment. The use of artificial intelligence makes it possible to create qualitatively new systems of environmental control and monitoring of the environment, with the ability to predict and prevent the dangerous situations. Recent events with man-made disasters in Russia and in the world have shown the importance of such systems.

It is especially important to improve the environmental and emergency monitoring systems for complex equipment and responsible technological processes. The dangerous or emergency situations threats to human life and health.

The environment monitoring is understood as the complex of the following properties:

- the property of the system to track changes in controlled parameters,
- the ability of the system to be adaptive,
- the ability of the system to make decisions in previously unpredictable and unanticipated situations,
- monitor the slow drift of the characteristics of the monitoring object,

- to predict the occurrence of an emergency situation before its real appearance,
- choose ways to prevent an accident.

The cost of eliminating man-made disasters can be measured in hundreds of millions of rubles, and the timing of the restoration of technical facilities and the environment — tens of years.

The main disadvantage of the currently used control and monitoring systems is to control the current situation, the lack of ability to predict the situation even in the near future. Systems simply track a number of parameters and make decisions based on their changes[1-4]. However, the change in parameters can be associated not only with violations of the current functioning of the equipment. The reasons for such violations can be not only instant refusals, but also gradual refusals, when there is an accumulation of negative influence, there is a certain negative trend.

It is proposed to use the complex of the artificial intelligence methods - fuzzy logic and neural networks. Using methods in the complex allows to obtain the new results. in environment monitoring

II. DEVELOPMENT OF FUZZY LOGIC MODELS FOR ENVIRONMENT MONITORING SYSTEMS

The known fuzzy logic methods were used as the basis for the development of the fuzzy logic model for environment monitoring, see Fig. 1.

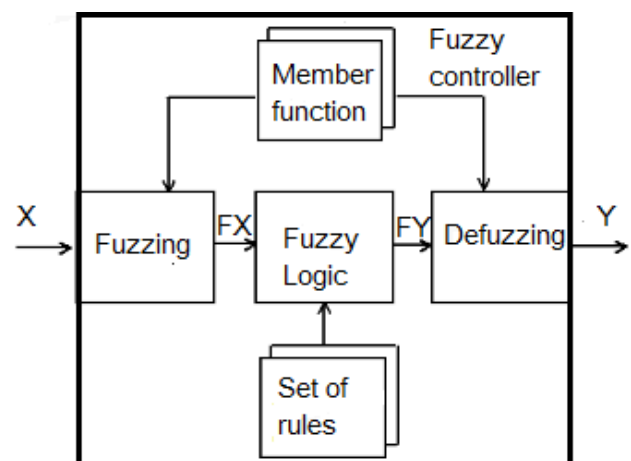


Fig. 1. Fuzzy logic model for environment monitoring

The requirements for the environment monitoring were described in the set of the fuzzy logic rules. The new

proposed fuzzy logic model allows changing in the set of the fuzzy logic rules and reprogramming the fuzzy controller.

The environment monitoring require significant expenses. A new method is proposed including fuzzy logic and neural networks with the switcher structure [5]. Switcher neural networks were described in patents[5-8]. Switcher neural networks are designed from the trained fragments and interconnected with the switchers.

The switcher neural network uses previously trained fragments. The results of training form the matrix of coefficients.

The training coefficients are stored in the switcher random access memory. The training coefficients can be exported, imported, duplicated and copied. This properties of the switcher neural networks allow to reduce the time and expenses on the neural network design and training. The neuron network and its fragments can be retrained. In retraining the new training coefficients are stored in the switcher random access memory.

It is proposed to realize the fuzzy logic model (fig. 1) as the switcher neural networks, see. Fig.2.

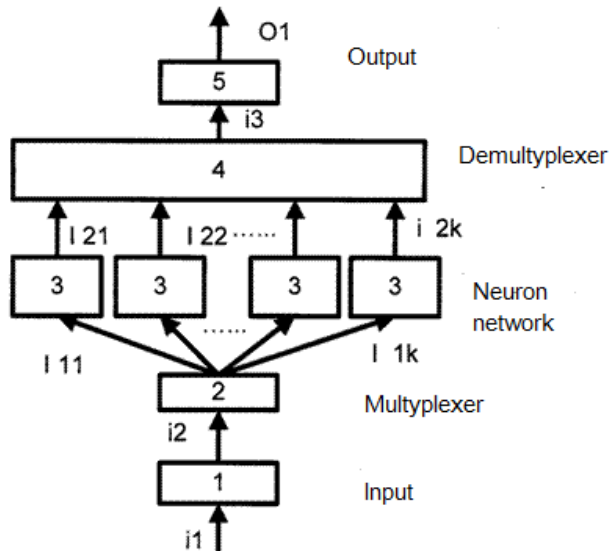


Fig. 2. The fuzzy logic model on the base of neuron networks

The fuzzy logic model on the base of neuron networks is represented in fig.2. The fuzzy logic model uses the neuron network rules and membership functions. The multiplexor and the demultiplexor can be realized as the additional switchers.

Fragments of switcher neural networks are trained independently of each other. The fragments are connected to each other using switchers.

The training coefficients neuron network are stored in RAM of switcher. The training coefficients can be imported, exported, copied, and replicated, without the need of the redesign and retrain of the entire neural network. The fragments of network are performed as the unified firmware modules. The scheme of the neural network module is presented in Fig.3. The interconnection of the switcher neural network modules is presented in Fig.4.

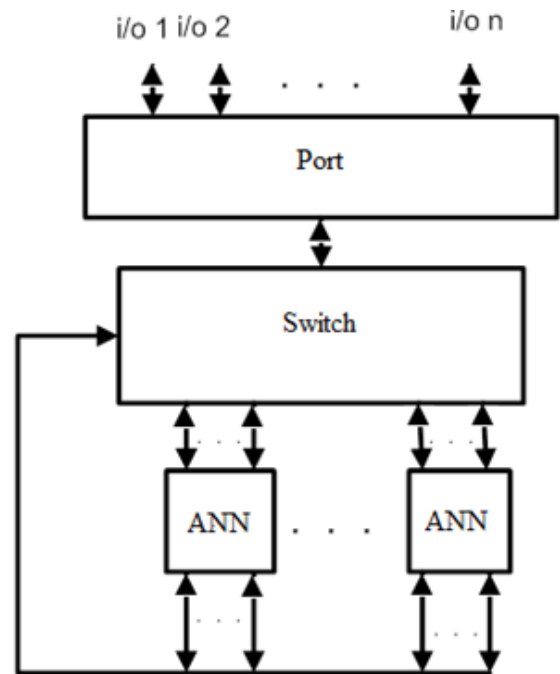


Fig. 3. The scheme of the neural network module, ANN-artificial neural network

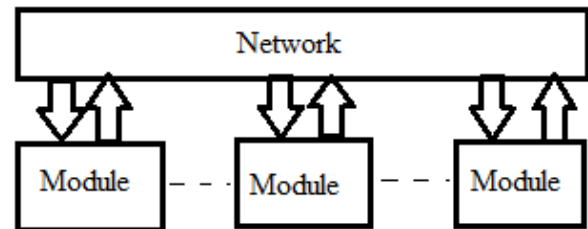


Fig. 4. The interconnection of the switcher neural network modules

III. THE FUZZY LOGIC MODEL FOR ENVIRONMENT CURRENT STATE ASSESSMENT

The fuzzy logic model was applied to assessment of the current state of environment.

The main fuzzy controller is presented in Fig.1,2. The input information is numeric value vector of sensor inputs X . X is put into the phasifier. The phasifier converts X into the fuzzy linguistic variable FX .

The phasifier uses the membership function FX , see Fig.5. The membership function defines the linguistic variable FX . The set of the input fuzzy linguistic variable FX

$FX \in \{\text{Low, Normal, High, Dangerous}\}.$

Then the set of fuzzy rules was applied to the FX . According to the rules we get the linguistic output variable FY .

The set of the output fuzzy linguistic variable

$FY \in \{\text{Reliable, Safe, Emergency, Alarm}\}$

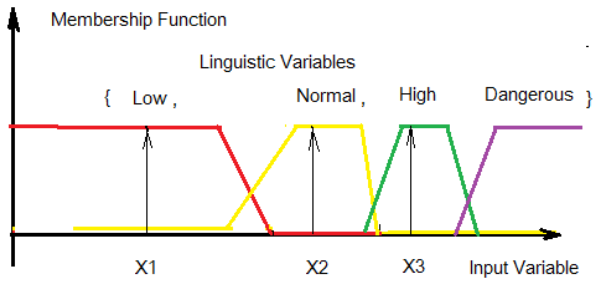


Fig. 5. Membership function of input linguistic variable FX

The set of rules is represented in the form of conditions
" If FX Then FY"

1. If Low Then Reliable
2. If Normal Then Safe,
3. If High then Emergency
4. If Dangerous then Alarm

The linguistic variable FY is put into the defasifier. The defasifier converts the linguistic variable FY into the control command Y. The defasifier uses the membership function of the linguistic variable FY, see Fig. 6. The command Y is formed in the output of the fuzzy logic model.

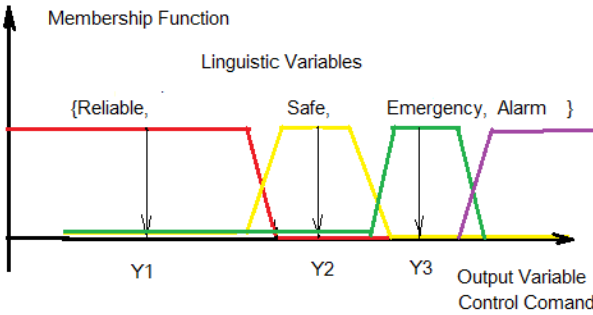


Fig. 6. Membership function of output linguistic variable FY

The set of rules is realized on the base of the switcher neuron network, see Fig.2. The proposed fuzzy logic model can be applied to future environment state prediction.

IV. THE FUZZY LOGIC MODEL FOR ENVIRONMENT FUTURE STATE PREDICTION

The fuzzy logic model was applied to prediction of the future state of environment.

The additional prediction fuzzy controller is presented in Fig.1. The addition input information is the prediction interval Dt. $Dt \in [0, T]$. Inputs Dt follow to the phasifier. The phasifier converts Dt into the fuzzy linguistic variable Ft

$$Ft \in \{ \text{Stable, Changeable, Undetermined} \}$$

The phasifier uses the membership function Ft, see Fig.7.

The main fuzzy controller defines the linguistic variable of current state FY. The set of the input fuzzy linguistic variables FY and Ft form the set of rules for future environment state prediction (FP).

$$FY \in \{ \text{Reliable, Safe, Emergency, Alarm} \}$$

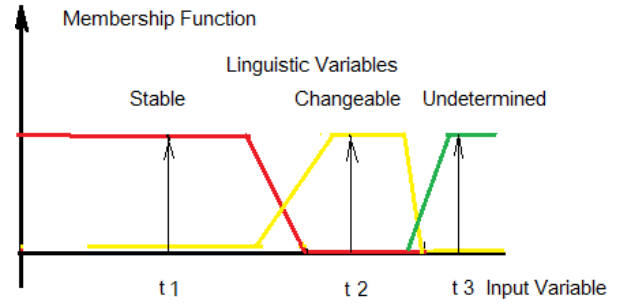


Fig. 7. Membership function of input linguistic variable Dt

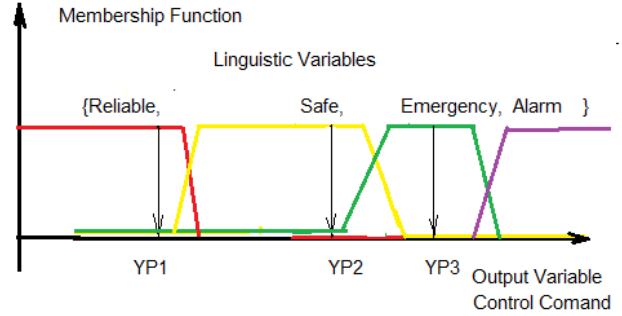


Fig. 8. Membership function of output linguistic variable FP

For example, the rules are:

1. If FY= Reliable and Ft = Stable Then FP= Reliable
2. If FY=Normal and Ft = Stable Then FP= Normal,
3. If FY= Emergency and Ft = Stable Then FP= Emergency
4. If FY= Alarm and Ft = Stable Then FP= Alarm
5. If FY= Reliable and Ft = Changeable Then FP= Reliable
6. If FY=Normal and Ft = Changeable Then FP= Normal,
7. If FY= Emergency and Ft = Changeable Then FP= Alarm
8. If FY= Alarm and Ft = Changeable Then FP= Alarm
9. If FY= Reliable and Ft = Undetermined Then FP= Reliable
10. If FY=Normal and Ft = Undetermined Then FP= Normal,
11. If FY= Emergency and Ft = Undetermined Then FP= Alarm
12. If FY= Alarm and Ft = Undetermined Then FP= Alarm

The linguistic variable FP is put into the defasifier. The defasifier converts the linguistic variable FP into the control command YP. The defasifier uses the membership function of the linguistic variable FP, see Fig. 8. The command YP is formed in additional output of the fuzzy logic model.

V. TECHNICAL IMPLEMENTATION OF ENVIRONMENT MONITORING SYSTEM

It is proposed to realize the fuzzy controllers on the base of the fuzzy logic[6] and neuron networks[7-8]. The neuron networks are realized as the unified firmware modules, see Fig.3,4. The fuzzy rules can be united in lays. So the environment monitoring system can be realized as the multilayered modular computing system [9]. Fragments of switcher neuron network are proposed to be implemented on the set of unified modules.

VI. CONCLUSION

Environment monitoring is the important and actual problem. To solve this problem, it is proposed to use the new artificial intelligence methods and fuzzy logic models. The objects of the research are the control systems for environment monitoring. The control systems get commands from operator and input signals from sensors. The output signals declare the current environment state and predict its changes in the future.

The fuzzy logic model of the environment monitoring was proposed. The fuzzy logic model is based on the neuron networks. Technical means for its implementation were proposed.

The fuzzy model for the environment monitoring can be used in automated control systems in mechanical engineering, in aviation and space, on transport, etc.

The results obtained can be useful when combined with the results of work [6], as well as works [9-10].

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Ethical Challenges of Applying Artificial Intelligence in Education: Issues in Developing Standards

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Abstract — The integration of artificial intelligence (AI) in education has the potential to transform teaching and learning processes, enhancing personalization, efficiency, and access to knowledge. However, its widespread adoption raises significant ethical challenges that demand careful consideration. This article explores the key ethical issues related to the use of AI in education, including transparency, bias, data privacy, accountability, and the potential for exacerbating existing inequities in educational systems. It also examines the ongoing difficulty of developing comprehensive ethical standards that balance innovation with social responsibility. By analyzing current frameworks and the gaps they present, the article underscores the need for a shared ethical approach to guide AI implementation in education, ensuring that technological advancements prioritize equity, fairness, and the well-being of learners.

Keywords — artificial intelligence (AI), ethics, education, risks, ethical standards.

I. INTRODUCTION

The history of artificial intelligence (AI) technology dates back to the 1950s, when initial attempts were made to create computer systems that mimicked human reasoning. It is believed that the term "artificial intelligence," in its modern understanding, was formalized during a scientific seminar organized by John McCarthy at Dartmouth College (USA) in 1956 [1]. For a long time, AI algorithms were successfully used to solve specific research and engineering tasks, such as optimizing data flows in telemetry, applied natural language expert systems, image analysis programs, and machine translation systems – all of which held independent value but were not fundamentally intelligent [2]. However, with the increase in computational power, the prospect of creating technical systems that simulate human thought processes became a reality.

The Russian national standard GOST R 59895-2021, "Artificial Intelligence Technologies in Education. General Provisions and Terminology," defines artificial intelligence as "a set of technological solutions that enable the simulation of human cognitive functions (including self-learning and problem-solving without a pre-defined algorithm) and achieve results comparable, at minimum, to the outcomes of human intellectual activity when performing specific tasks" [3].

Despite the clear benefits and promising applications of AI technologies in education, the ethical issues and risks associated with them are causing justified concern within the professional community. Several questions arise, for which

there are no definite answers as of yet. For instance, what impact might artificial intelligence have on universal human values and social progress? Can the safety of individuals and the protection of personal data be ensured? How will education and the labor market change? Will artificial intelligence remain accountable to humans? Currently, amidst significant uncertainty in predictions and inadequate mechanisms for national and international regulation of AI, such issues can mostly be addressed within the frameworks of ethics, morality, and values.

The British scientist Alan Turing proposed a method for evaluating the intellectual capabilities of machines, which later became known as the "Turing Test." According to this test, a computer can be considered to possess artificial intelligence on a human level if it can engage in textual dialogue with a person in such a way that the interlocutor cannot distinguish whether they are conversing with a machine or a living person. In recent years, examples of computer programs based on big data and deep learning neural networks capable of "passing" the Turing Test have emerged. This has raised serious concerns among scientists, experts, and the public, as the rapidly evolving AI technology can not only drive progress but also pose significant threats to humanity [4].

This means that the rules and algorithms governing AI are determined by a group of people – developers or users – based on their own concepts of conscience, good and evil, freedom and necessity, the balance between reason and emotion, and the responsibility of choosing between individual and societal needs [5].

Experts believe that the threat of a "machine uprising" is unlikely in the near future. The primary risks are associated with the human factor in applying these technologies and must be addressed in the realms of ethics, morality, and responsibility [6].

In essence, this involves forming a shared conceptual framework regarding both the AI technology itself and the people who develop and apply it. This framework could serve as a foundation for legislative and regulatory oversight in this field, as well as for public and professional reflection [7].

II. CURRENT STATE OF AI APPLICATION IN EDUCATION

At present, the growth rate of artificial intelligence can be described as rapid. This is driven by technological advancements in machine learning and computing, substantial private and government investment, the widespread adoption of AI in numerous fields, including education, the global availability of AI technologies for study

and development, and the growing demand for business process automation and increased efficiency. According to a report by Grand View Research, Inc., the AI market is expected to grow at an average annual rate of 36.6% from 2024 to 2030, reaching 1,811.75 billion USD by 2030 [8]. Data from Global Market Insights indicates that the AI market in education reached 4 billion USD in 2022 and is forecasted to grow by more than 10% annually between 2023 and 2032.

The world's leading countries see the development of AI as the key to strengthening their national competitiveness and security. In 2019, Russia approved the National Strategy for the Development of Artificial Intelligence until 2030. This document sets goals and objectives for AI progress in the country and provides measures for using AI in the interests of strategic priorities, including scientific and technological development. Progress in AI is considered a key factor for the success of the country's digital economy. Artificial intelligence has also been identified as a priority technology in the National Technology Initiative (NTI), within which the Competence Center for "Artificial Intelligence" was established at the Moscow Institute of Physics and Technology. To integrate the efforts of stakeholders from academia and business, the Alliance for Artificial Intelligence was created, which initiated the adoption of an Ethics Code in the field of artificial intelligence [9].

As UNESCO, the United Nations agency specializing in education, science, and culture, notes, artificial intelligence today has the potential to address some of the most significant challenges in education, introduce innovations into teaching practices, and accelerate progress toward achieving sustainable development goals [10]. The concept of "Artificial Intelligence in Education" (AIED), as defined by UNESCO, encompasses any educational products and services based on or utilizing AI technologies, as well as educational environments and additional resources.

A review of research on artificial intelligence in education shows that this technology can enhance education management, improve the educational process, expand the possibilities for teaching and learning, increase the potential of educators, promote diversity in learning formats and assessment methods, and cultivate values and skills that align with technological progress [11]. The most relevant areas and priorities for AI in education include personalized learning, adaptive learning systems, automation of administrative tasks, intelligent tutors and assistants, learning analytics and performance forecasting, intelligent knowledge assessment, interactive and gamified learning, translation tools for foreign languages, speech-to-text and text-to-speech conversion, inclusivity tools, applications for self-reflection and the professional development of teachers, safety monitoring in educational institutions and online, support for scientific research and innovations through AI-driven big data analysis, generative systems for creating text and multimedia content, real-time feedback systems, and more [2, 3, 10, 13, 16].

The most pressing aspects of this field involve studying the potential of artificial intelligence for education and the associated risks, including social and ethical implications, as well as forming a unified framework for discussing and drafting agreements, legislative, and regulatory documents. In this regard, the first steps have already been taken. Firstly, the concerns of the professional community are reflected in national and international declarations and ethical codes, which articulate the general principles relevant at the time of their adoption. Secondly, international standards for the

development and use of AI technologies have been published, addressing technical and organizational issues, as well as aspects of ensuring quality, trust, reliability, and safety [12]. In Russia, according to the Federal Agency on Technical Regulating and Metrology (Rosstandart), over 60 national standards for AI have been issued under the national standardization system GOST R, including for the field of education and science. The next step is the updating and supplementation of these standards to reflect the pace of AI technological advancements and ongoing technical and social progress.

III. THE ROLE OF STANDARDS

Standards provide a unified set of requirements and recommendations that can be consistently applied across various levels and in different contexts. This promotes coherence in the implementation of ethical principles and practices. Unlike codes and declarations, standards primarily contain specific, measurable procedures and criteria that can be verified. Standards offer more detailed practical guidance for the implementation of ethical principles, making them a valuable tool for AI developers and educational organizations. They can serve as a foundation for drafting laws and regulatory documents, ensuring the translation of ethical principles into legally binding requirements. Standards developed by international organizations can contribute to global consistency in the use of AI in education. Compliance with standards in the form of certification or self-declaration can be used by AI producers to demonstrate the quality and reliability of products and services to stakeholders, including educational institutions, parents, and regulators. Moreover, standards can crystallize and formalize best practices, ensuring the widespread dissemination of valuable knowledge and expertise. Overall, standards complement other ethical tools by providing a more rigorous, systematic, and practical foundation for the ethical use of AI in education.

Other Russian standards in this series address issues of adaptive learning [13, 16], requirements for the collection, storage, processing, transmission, and protection of data [14], quality issues of AI systems [15], and requirements for control data samples used in testing AI systems in education [17]. The ethical issues of AI are partially addressed in the standard GOST R 59276-2020, "Artificial Intelligence Systems. Methods for Ensuring Trust" [18], which defines the concept of trust, provides a classification of factors that affect the quality and ability of AI systems to inspire trust at lifecycle stages, formalizes the relationship between quality and the ability of AI systems to inspire trust, and gives a classification of key methods to ensure trust in AI systems. This document is primarily aimed at developers but is also useful for consumers.

IV. METHODS OF THE RESEARCH

The identification of stakeholders in the regulation of ethical standards for the use of artificial intelligence in education took place from February 2024 to March 2025 at the "Boiling Point Saint Petersburg" coworking spaces in the format of round tables and expert sessions. Around 300 representatives of educational organizations and IT specialists participated, including leaders, administrative staff, teachers, and experts.

The events were organized into four sessional blocks, each with its own thematic focus, lasting approximately half a working day. Participants were assigned to groups in

advance to ensure representation across all segments of the education sector and foster a diverse dialogue.

The first session was devoted to identifying all participant groups that are directly or indirectly interested in regulating ethical aspects of AI usage in education. Participants discussed the roles of students, parents, public organizations, IT companies, government bodies, and educational institutions themselves. The format included brainstorming and panel discussions.

The second block focused on discussing the interests of each group and potential conflicts that could arise during the integration of AI into the educational process. For instance, universities emphasized scientific breakthroughs and the development of innovative programs, while schools and preschools prioritized ethical considerations and data security for children. Participants created "problem maps" to identify key intersections and potential contradictions among stakeholders.

The third session aimed to establish foundational principles for interaction between stakeholders. Special attention was given to issues of transparency, adherence to ethical standards, data protection, and minimizing risks for education.

The fourth session was dedicated to the development of procedures, tools, and methods for addressing ethical issues of AI in education, with the participation of AI developers.

The session focused on fostering collaboration between educators, AI experts, and policymakers to establish frameworks that ensure responsible and ethical use of artificial intelligence in educational processes. Discussions included topics such as data privacy, algorithmic bias, transparency, and the potential impact of AI on students' learning outcomes and educators' roles. Participants aimed to create actionable solutions that align technological advancements with ethical standards and values in education.

The round tables were organized by a working group comprising moderators, a technical team, and student volunteers.

V. RESULTS OF DESIGNING FRAMEWORKS FOR AI ETHICS IN EDUCATION STANDARDIZATION

When developing the framework for an AI ethics standard in education, reference can be made to the ISO/IEC TR 24368:2022 technical report, titled "Information Technology. Artificial Intelligence. Overview of Ethical and Social Issues" [19]. Although this report primarily outlines preliminary agreements within the professional community as a guideline for standard development, it provides a list of stakeholders for whom ethical considerations in AI applications in education are significant, along with recommendations for identifying and addressing these concerns.

Based on the typology and practice of standards application, the regulation of activities related to AI ethics in education should align with the format of management system standards [20]. These standards propose universal recommendations, agreed upon by the expert community, which can be applied to effectively achieve an organization's main objectives by systematically considering ethical aspects of management. A standardized system ensures organizations adopt a structured approach that is comprehensible to all stakeholders and suitable for achieving benefits from the

establishment of clear procedures and guidelines for specific tasks.

Standardization in the field of AI ethics is a challenging task because it intersects with difficult-to-formalize categories and dilemmas related to human existence, moral and ethical decision-making based on conscience, and societal ethical norms. Nevertheless, applied branches of ethics, such as professional ethics, and specifically the ethics of science and education, allow for the development of procedures to resolve moral conflicts within specific areas of social practice. These procedures help in addressing human priorities, dignity, human rights, ontological traits of personality, and other aspects of general ethics [6].

Thus, an ethics standard could serve as a key element in ensuring responsible and safe development of education through the use of artificial intelligence. A crucial question arises: what is the target audience for such a standard? Will it be equally relevant for educational institutions and AI development organizations, or should these be separate standards? Are there other potential users interested in an ethics standard for education? These questions evidently require open discussion, justification, and consensus from both the public and experts.

The ISO Technical Committee ISO/TC 232 "Learning Services for Education and Training" has initiated the development of a standard with the working title: "Educational and Training Services. Digital and Distance Learning. Framework for Embedding Ethical Concerns in Artificial Intelligence (AI) in Education." This standard will cover the structure of risks associated with AI application in education, ethical principles, roles of participants in the educational process and AI application developers, methods for expert evaluation of ethical considerations, and recommendations for developers, participants, management, and monitoring. Since the structure and content of the standard are still being defined, it is vital to participate in open discussions and publications to shape the content of this document, enhancing its significance and relevance for end users.

A. Stakeholders in regulating ethical standards for the use of AI in education

Based on the results of organized round tables and expert sessions, we have identified the main stakeholder groups, their needs, level of interest, and degree of influence, which are presented in Table 1.

TABLE 1. STAKEHOLDER ANALYSIS. (DEVELOPED BY THE AUTHORS)

Stakeholders	The need for standardization	Level of interest	Level of influence
Educational organizations	Implementation of ethical AI-based solutions aligned with the mission and values of the organization	high	high
Students	Ethical use of data, protection of personal information, and fair assessment of outcomes	high	middle
Teaching staff	Reducing routine workload in the process of automating the educational process while preserving the teacher's role	high	high
AI developers and technology companies	Development of products and services not only meeting regulatory requirements but also universal human values and principles of business	high	high

Stakeholders	The need for standardization	Level of interest	Level of influence
	integrity		
Parents and legal representatives	Children's safety, including psychological well-being, and maintaining the quality of education when using AI	high	middle
Government and regulatory bodies	Standardization of AI application procedures to ensure compliance with legislation and ethical evaluation	high	high
Non-governmental organizations and associations	Promoting accessibility and equity in education, preventing discrimination, and upholding human rights	high	middle
Experts in ethics and law	Establishing ethical frameworks and evaluation procedures for laws and regulations	high	middle
Research institutes and academic circles	Creating a unified conceptual framework for scientific research in AI and fostering academic integrity	middle	middle
The public and media	Transparency and accountability of AI systems, public awareness campaigns	middle	middle
Investors and financial organizations	Corporate social responsibility in developing and using AI, building a reputation for good faith, and prioritizing sustainable development	middle	middle
Trade unions	Protection of labor rights in the face of automation, providing resources for professional development of educators in connection with AI implementation	middle	middle

B. Ethical principles that can be included to the standard

Ethical principles for the application of AI in education that may be standardized should ensure fair, effective, and safe use of technology for all participants in the educational process. Based on a review of publications and an analysis of various approaches, we have attempted to describe and systematize ethical principles that can be recommended for inclusion in the standard:

- respect for personal autonomy, including the right to make decisions without interference from AI;
- ensuring equal access to resources and fair distribution of both benefits and burdens;
- preventing and eliminating discrimination and bias;
- transparency, understandability, and explainability of AI decision-making processes, along with accessible information about the functionality and goals of AI systems;
- clear definition of responsibility for AI decisions and actions, including mechanisms for accountability and compensation in cases of harm;
- confidentiality and protection of users' personal data during AI usage, including adherence to data minimization principles and obtaining consent for data processing;
- the principle of minimizing harm, including the prevention of risks and unintended consequences of AI use;
- respect for human dignity during interactions with AI and preventing humiliation or dehumanization;

- considering social and environmental impacts during AI development and implementation, including sustainability and long-term consequences for humanity and the environment;
- promoting broad interdisciplinary collaboration in developing and utilizing AI, ensuring the inclusion of all stakeholders;
- ensuring equal opportunities for access to AI-managed educational resources for all learners, regardless of their socio-economic status, location, or abilities;
- pedagogical effectiveness for achieving better outcomes;
- the principle of preventing harm to learners and educators;
- social responsibility regarding AI's impact on the social aspects of education, including fairness, inclusivity, and social interaction;
- the right to choose alternative learning options, including the ability to opt out of automated solutions;
- encouraging critical thinking and analytical skills among learners, not merely transferring knowledge;
- regular assessment of AI's impact on educational processes and outcomes, as well as monitoring its compliance with ethical standards;
- establishing mechanisms for collecting and considering feedback from learners, teachers, and parents on the use of AI in education;
- supporting the use of AI to foster creative and innovative approaches in education, while maintaining a critical view of potential risks and limitations;
- implementing ethical evaluation processes for new AI tools and methods before their application in the educational environment;
- guaranteeing academic freedom and teacher autonomy in choosing teaching methods;
- psychological well-being of learners and educators, especially concerning the stress and workload associated with AI technologies;
- providing resources and professional development programs for educators so they can effectively integrate AI into their teaching practices;
- encouraging experimentation and research on AI in education to promote continuous improvement and innovation while adhering to ethical standards;
- striking a balance between technological and traditional teaching methods, ensuring AI complements rather than replaces core pedagogical approaches;
- developing adaptive ethical principles that can be modified depending on context, cultural characteristics, and changes in the educational environment.

The implementation of these principles requires joint efforts from all stakeholders and can be achieved through policies of educational organizations and AI developers, as well as procedures for their application, monitoring, and improvement.

C. Risks associated with ethical issues of AI implementation in education

Based on a review of publications [1, 2, 4, 7], we have summarized the main groups of risks associated with the use of AI in education for inclusion in a standard, as follows:

- increased inequality in education due to the cost of internet access and hardware requirements;
- misleading children and adults by generating false or fake content, data, information, and media;
- incorrect but plausible educational recommendations, instructions, and resources that could lead to more serious consequences when related to safety, health, or social phenomena;
- the risk of increased workload for educators and other educational staff due to the need to invest time in learning new technologies and re-planning educational content;
- the risk of losing valuable traditional life skills, essential attributes, and aspects of education as a result of reduced or lost interaction through in-person or distance-based educational technologies;
- incorrect assessment results of educational outcomes, particularly in creative fields of study;
- bias toward different groups of learners based on gender, race, or other characteristics;
- the threat of unequal opportunities for education or employment due to potential false criteria and algorithms;
- potential issues related to the physical and mental health of participants in the educational process as a result of interacting with artificial intelligence.

D. Procedures and tools to support an ethical strategy

It is advisable to include the following risk management tools in AI ethics standards for education:

- development of ethical guidelines for all participants involved in the development, implementation, and use of AI in an educational context;
- educational programs for teachers, administrators, and students on AI ethics, including understanding how AI works, its potential impact on educational processes, and data privacy issues;
- feedback and complaint mechanisms: creating channels for receiving feedback and handling complaints from students, parents, and teachers regarding AI use;
- stakeholder participation in decision-making processes related to AI use in education;
- cross-cultural adaptation of standards and practices to local conditions;
- establishment of independent oversight bodies to ensure compliance with ethical standards and resolve disputes related to AI;
- promoting research on AI ethics to explore the ethical aspects of AI use in education;
- access to legal support and consultation for students and teachers in cases of ethical issues related to AI;

- integration of ethics into educational standards and curricula;
- fostering and supporting ethical leadership to promote and uphold ethical standards in AI use;
- supporting research ethics in ai-related projects to ensure honesty, transparency, and respect for participants' rights;
- creating policies for managing changes associated with AI implementation;
- including students in the development and testing of AI systems so they can contribute and express their needs and concerns;
- establishing benchmark datasets to assess and compare AI systems in terms of their ethics, efficiency, and impartiality;
- ethical training for AI developers to better understand the social implications of their work;
- collaboration with ethics committees, alliances, and councils to ensure proper review and approval of AI projects;
- supporting the development and use of open AI platforms, allowing the community to contribute to improving and validating technologies;
- ensuring research results are accessible to the public, fostering transparency and open discussion;
- preparing for unforeseen consequences of AI use, including contingency plans for system failures, prediction errors, and other potential issues;
- supporting public dialogue on AI's impact on education to ensure transparency and community involvement;
- periodically reviewing AI use to improve and update ethical standards and practices;
- building partnerships with parents and legal guardians to ensure support and understanding of AI-related changes in education.

It is also advisable to include the following risk management procedures in AI ethics standards for education:

- procedures for conducting ethical audits and assessing human rights impacts for new AI-based products and services before their implementation in educational practice;
- procedures for ensuring data privacy during the collection, storage, processing, and transfer of personal data, including securing consent for processing and the ability to delete data;
- procedures for accountability and compensation to address incidents related to AI and correct errors;
- procedures for ensuring algorithm transparency, including access to information on decision-making processes and opportunities for explanations;
- procedures for monitoring ethical aspects;

- certification and accreditation of AI-based educational programs and tools to ensure their compliance with established ethical norms and educational standards.

- procedures for inclusive education and accessibility for students with special educational needs;

- development of self-assessment tools enabling educational institutions to independently evaluate their AI practices from an ethical standpoint and for standards compliance;

- oversight of funding sources for AI research and development in education to avoid conflicts of interest;

- implementation of procedures that consider socioeconomic factors and inequalities in access to AI-based educational technologies;

- ethical design of AI interfaces to ensure they are user-friendly, inclusive, and appropriate for varied levels of technical literacy;

- ethical stress-testing of AI systems to verify their reliability and safety in complex scenarios;

- procedures for assessing AI's long-term impact on educational systems and society, including potential changes in labor markets and skills required for future generations;

- risk management procedures associated with AI use in education, including identifying and analyzing them.

- managing conflicts of interest, particularly concerning commercial interests in educational AI projects;

- procedures for social responsibility and sustainability: encouraging the development and use of AI systems that contribute to social responsibility and sustainable development.

These procedures and tools should be interconnected and aligned with relevant legislative and regulatory acts to create a comprehensive and effective approach to ensuring AI ethics in education. They must be embedded in the educational system at all levels, from policy to practice, and be regularly updated to reflect the latest technological and social changes.

VI. CONCLUSION

Thus, the integration of ethical standards into educational practice will contribute to the creation of a fair, inclusive, and innovative educational environment where AI is used solely to improve the quality and accessibility of education and cannot harm individuals. However, business competition will always exert pressure on AI developers who aim to reduce costs, including expenses for testing and evaluating the potential negative consequences of their products and services. As a result, whether intentionally or unintentionally, they may introduce unverified solutions into the education market [22]. In this regard, it is crucial to enhance the awareness of all stakeholders about the potential and challenges associated with using AI in education to establish a foundation for the ethical, responsible, and effective application of AI that improves educational outcomes. It is necessary to develop a common framework for discussing the issues of AI use in education within professional and public domains, including through awareness-raising and training efforts, to ensure that AI development and application take into account human rights and well-being.

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Integrating Information and Parametric Modeling for the Design of Steel Truss Bridges

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Abstract—This article describes a dynamic approach to integrating information and parametric modeling for the design of steel truss bridges. The Grasshopper visual programming language is utilized for creating parametric scripts, and the model is able to integrate into information modeling tools such as Tekla Structures for additional details and analysis software for strength calculations. The integration of the truss parametric model into numerous software packages has improved the design automation process, saving time and effort. In comparison to traditional design methods, this approach makes the process of building a complicated structure like a bridge considerably simpler and more efficient. Each design element can influence others, resulting in a network of interrelated parameters. The results show significant improvements in time savings, alternative design selection, and structural performance. Furthermore, this approach has the potential to revolutionize bridge design, leading to more cost-effective and efficient structures that meet modern transportation infrastructure demands.

Keywords—bridge, information modeling, parametric modeling, truss, visual programming.

I. INTRODUCTION

Efficient transportation networks are essential for ensuring that urbanization results in sustainable development, economic growth, and improved quality of life. In every country, bridge development is essential in order to improve the transportation infrastructure network because they often provide the most direct and efficient route to travel between different areas, reducing travel time and fuel consumption. In recent years, due to the widespread use of Building Information Modeling (BIM) technology, the process of designing, constructing, and operating bridges is entirely changing from traditional Computer Aided Design (CAD) systems. Currently, the advancement of instrumental assistance for architectural and construction design is linked to the integration of its components into a single system based on BIM technology [1].

Conventional bridge design methods rely heavily on two-dimensional (2D) drawings as the primary means of communicating project specifics to stakeholders [2]. Despite advances in CAD software that have increased drafting efficiency, these 2D-focused methodologies continue to have limitations in allowing collaborative efforts and interdisciplinary evaluations, which are critical in complex bridge engineering projects [3]. Because of the lack of centralized data management, interactions between design, analysis, and construction teams are usually fragmented, inefficient, and error-prone [4]. Traditional design methodologies are typically not compatible with advanced technologies.

Information modeling technology is a transformative approach in bridge engineering, offering a digital representation that integrates various facets of a bridge's physical and functional characteristics throughout its lifecycle. The information model presents a three-dimensional representation of the complete structure as well as its individual components, providing that any changes are automatically reflected in the related documentation [5, 6]. Since information modeling entails the automation of information utilization, it represents a greater level of design automation. BIM extends beyond traditional 3D modeling by incorporating 4D (time) and 5D (cost) elements [7, 8], which are crucial for the lifecycle management of bridge projects.

From proposal design to construction and maintenance processes, the application of BIM in bridge engineering improves the data management among the participants. BIM also enhances the detailed model visualization and pre-construction analysis. Currently, BIM technology is widely used in bridge engineering for various purposes, including design and project planning and structural analysis. Consequently, BIM facilitates more efficient resource utilization and cost management, setting a new standard in the bridge construction sector in many countries.

II. BIM-BASED PARAMETRIC MODELING

Although BIM softwares are among the most capable technologies for modeling both simple and complex structural components, they frequently struggle with the complexities of curved surfaces and non-linear geometries. BIM tools struggle with curved geometries for a variety of reasons, including their design focus on linear structures, which results in restricted parametric possibilities for complex shapes like curved road and bridges [9]. Curved geometries increase data complexity and can lead to issues with performance, although industry standards largely prioritize rectilinear designs [10]. In addition, interoperability issues develop when combining with specialized applications, complicating modeling efforts. Plus, current construction methods are primarily linear, creating constraints that prevent the efficient use of BIM for non-linear designs, resulting in ongoing limitations in the technology. Furthermore, bridges typically differ significantly in both geometry and meaning between structures, which makes it challenging to use pre-existing BIM data formats. Nowadays, the majority of companies utilize the same structural design method, in which the creation of the design is based on a single choice made through a step-by-step process. When adjustments are needed, this is a laborious procedure that frequently necessitates starting over from scratch with the design, which is undesirable for large and complex structures [11].

A relevant concept is the BIM-based parametric modeling. Recent works indicate using a parametric design approach is one way to increase design efficiency and interoperability [12]. A parametric design technique allows for easy adjustment of the "parameters" or "variables," which allows for the creation of several versions in search of the optimal solution. The parametric modeling allows for easy and dynamic design changes for both simple and complex structures. BIM technology with visual programming-based parametric modeling is the new development of bridge design methods.

The combination of BIM and parametric modeling is attracting the most attention at the moment. With the help of parametric modeling, engineers can automate repetitive design tasks and create customized workflows. This workflow also results in increased software possibilities to design complex geometry. Currently, one may develop a parametric model utilizing software such as Grasshopper or Dynamo. These visual programming tools are quite simple to use, and external data can also be used as model inputs.

One of the powerful tools that BIM has introduced to the construction industry is Grasshopper, a parametric modeling program. Not only does it simplify the design process of complex bridge models, but it also increases accuracy and speeds up design changes. Grasshopper allows designers to create complex structures by combining simple design components into an interconnected system. With this method, users can easily create and edit parametric models without having to manually change each component, raising BIM to new levels. The design possibilities increase significantly when the flexible visual programming of Grasshopper is combined with the dynamic capabilities of parametric BIM.

III. METHODOLOGY

In this article, the parametric truss model is created in Grasshopper, a Rhinoceros 3D add-on that uses a visual script, and then transferred to BIM Tekla Structures via the Grasshopper-Tekla Structures Live Link. The model can also be integrated into BIM calculation programs by direct link or export. This approach seeks to streamline the design process, increasing productivity while decreasing the likelihood of errors. Modifying key parameters allows for faster modeling of alternate designs, increasing the overall efficiency of truss bridge modeling. Operators can construct a parametric workflow with no prior programming skills by connecting BIM software like Tekla Structures to visual programming tools like Grasshopper.

IV. MODELING THE PARAMETRIC TRUSS

The authors developed the parametric truss bridge by defining design objectives and specifications such as shape, dimension, and material properties inside the Grasshopper.

When the design changes, the user only needs to enter the parameters in Rhino Grasshopper, and Tekla Structures automatically updates the entire structure. The integration of information modeling and visual programming programs is presented in Fig. 1. Once a Grasshopper model is completed, it can be used as a template for future projects by linking it to a database. Based on aims and restrictions, various truss designs can be optimized when all structural components remain coordinated. This integration enables more complicated geometries and quicker operations, considerably improving the design and construction processes.

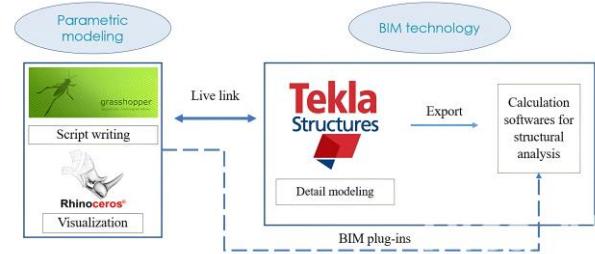


Fig. 1. The integration of information and parametric modeling.

To develop an algorithm-aided script for a truss structure in Grasshopper, first define the design parameters, such as span length, truss height, and number of panels, which will serve as an initial basis for the design process [13]. Next, create a baseline to represent the bridge span and use the 'Divide Curve' component to split it into panels, adjusting the length and width. To parametrically and symmetrically model the truss, the baseline must be an interpolated curve through a set of points. Construct the upper and lower chords of the truss by connecting vertical supports with the "Line" component after establishing a truss pattern or use the plug-ins.

Adjust design parameters using information visualization and optimization techniques to obtain the optimal combination of performance and material efficiency. Then, document and finalize the design by arranging the Grasshopper script, developing a user-friendly interface for parameter adjustments, and preparing output geometries for Rhino to represent the optimized truss bridge. For the bottom chord, for example, the bridge guide line is offset in both the x and -x directions and separated into particular points, which can then be interpolated and represented as a parametric curve. Next, define the truss and link it to the Tekla Structures plug-in for steel selection and installation. By defining and combining the truss element scripts, a combined network develops to construct the structure. Key steps of the process to create a parametric truss model are shown in Table 1.

TABLE I. KEY STEPS OF THE PROCESS TO CREATE A PARAMETRIC TRUSS MODEL

Step	Process in Grasshopper
Defining parameters	Define key truss parameters such as span length, height, number of panels, and member sizes.
Data input	Add any text input or structure complex numerical inputs as required.
Creating truss geometry	Create the main nodes of the truss, typically defining the top chord and bottom chord nodes based on input parameters. Connect the top chord and bottom chord nodes. Adjust the width and height using the parameters defined earlier. Diagonals can be created using a combination of the Line component in conjunction with List Item or Series to connect points appropriately, forming the triangulated sections of the truss.
Setting up the truss	The members created with the Line component can be grouped using the Join Curves component, which creates a more manageable truss geometry. Use Move if necessary to layer or offset the members for clarity in visualization.
Structural analysis and further detailing	Link to BIM software using live links or plug-ins.
Outputs and visualization	Adjust slider values to explore different configurations and design options dynamically. For better aesthetics, assign materials or change colors based on member types using Color Preview. Incorporate features for optimization to automatically search for the best configurations based on predetermined criteria.

The parametric steel truss is developed using the Grasshopper visual programming interface (Fig. 2). The width, height, and bracing system of the truss bridge are among the user-controlled variables. When these user-specified parameters are combined, the truss design is generated. Users can enter data, modify it, and develop solutions ranging from basic geometric shapes to complicated structures using Grasshopper's visual

programming interface. However, careful customization is required to define parameters and constraints in a parametric model. To manage the complexity and the location of the truss points, a programming script can be added to the model. The truss development can be separated into upper and lower sections, as well as left and right sides, with each side capable of independent design.

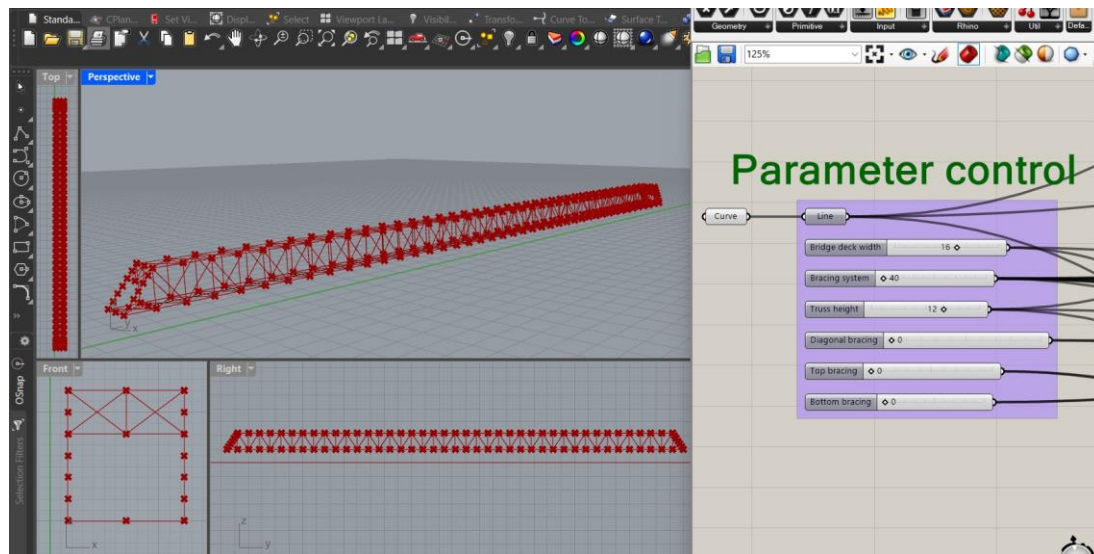


Fig. 2. Parametric steel truss model.

The creation of a superstructure is usually one of the most difficult aspects for designers due to the uniqueness of the input data, which is a guide curve for the bridge [14]. However, Grasshopper simplified the process by providing several plug-ins and graphical components from which input data is obtained and outcomes are generated, which are simple to use regardless of text-based instructions. In parametric modeling, the script designer will provide the input parameters. With this input, the model has all of the information it has to generate the geometry and then perform

all analyses and calculations. To speed up the process, the geometry of a complicated bridge structure may be divided into the main bridge, approach bridges, and substructure. However, there is also a visual model that combines all of the individual sections. After developing all the components of the structure, the user can decide how to optimize the design. The script developed for the parametric truss model is shown in Fig. 3. This optimization procedure will finally result in the preliminary design stage with minimum time and effort.

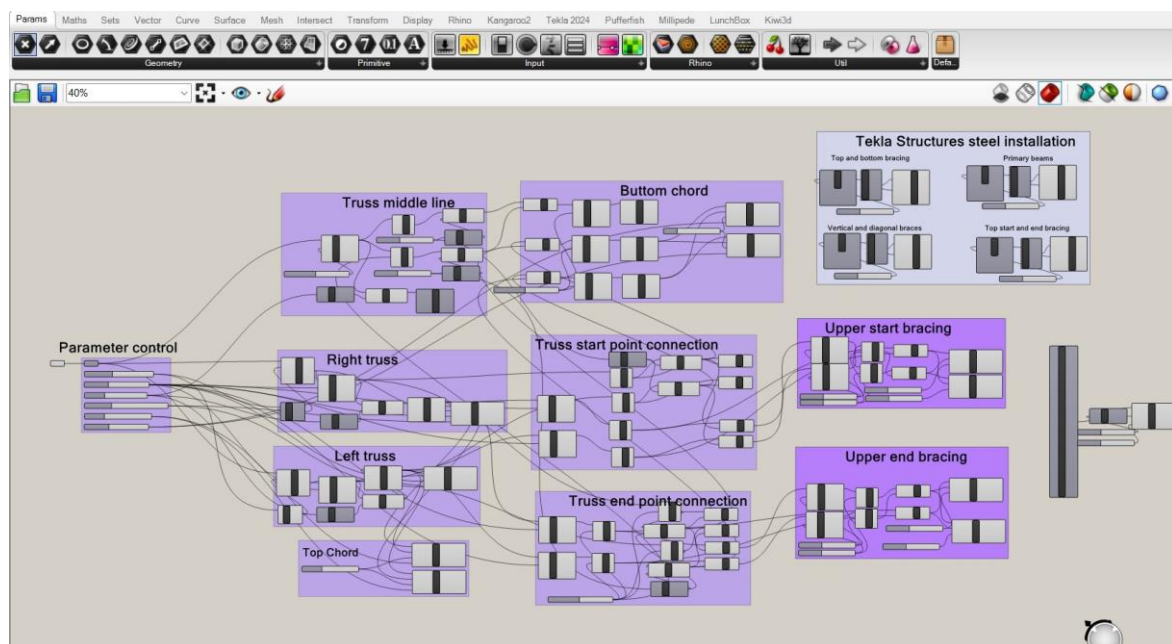


Fig. 3. The script for the parametric truss in Grasshopper.

When modeling the truss structure, the Tekla Structures plug-in within Grasshopper provides a choice of steel profiles widely used in bridge construction. The profile selection and installation (position, rotation, and attributes) can also be parametrically generated. Fig. 4 shows an example of steel profiles and the installation of the truss. The algorithms for each truss element are created using plug-ins, and due to the interconnected attributes, the model adjusts automatically (Fig. 5). The selected steel profiles can then be linked to specific parts of the truss structure, and as soon as the user changes the parameter in Grasshopper, the model will update in Tekla Structures (Fig. 6).

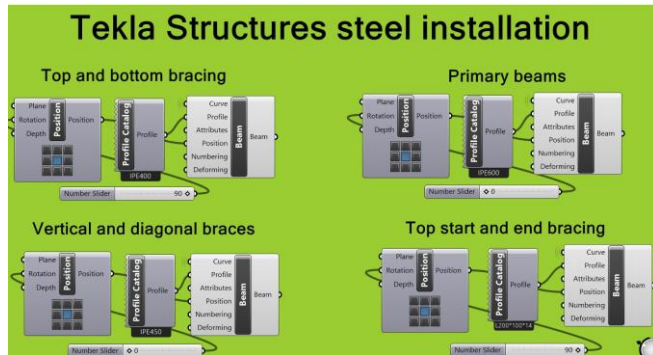


Fig. 4. Steel sections and installation from the Tekla Structures plug-in.

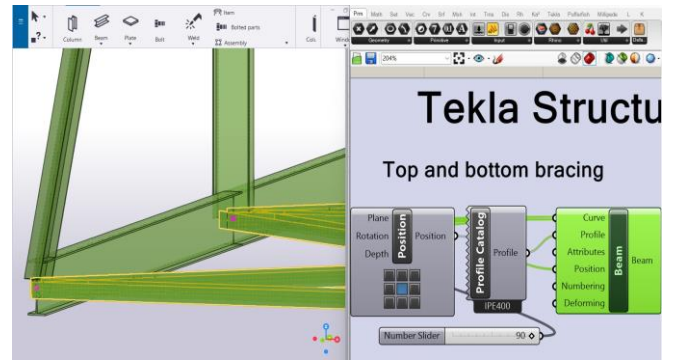


Fig. 5. Design changes are automatically updated in Tekla Structures.

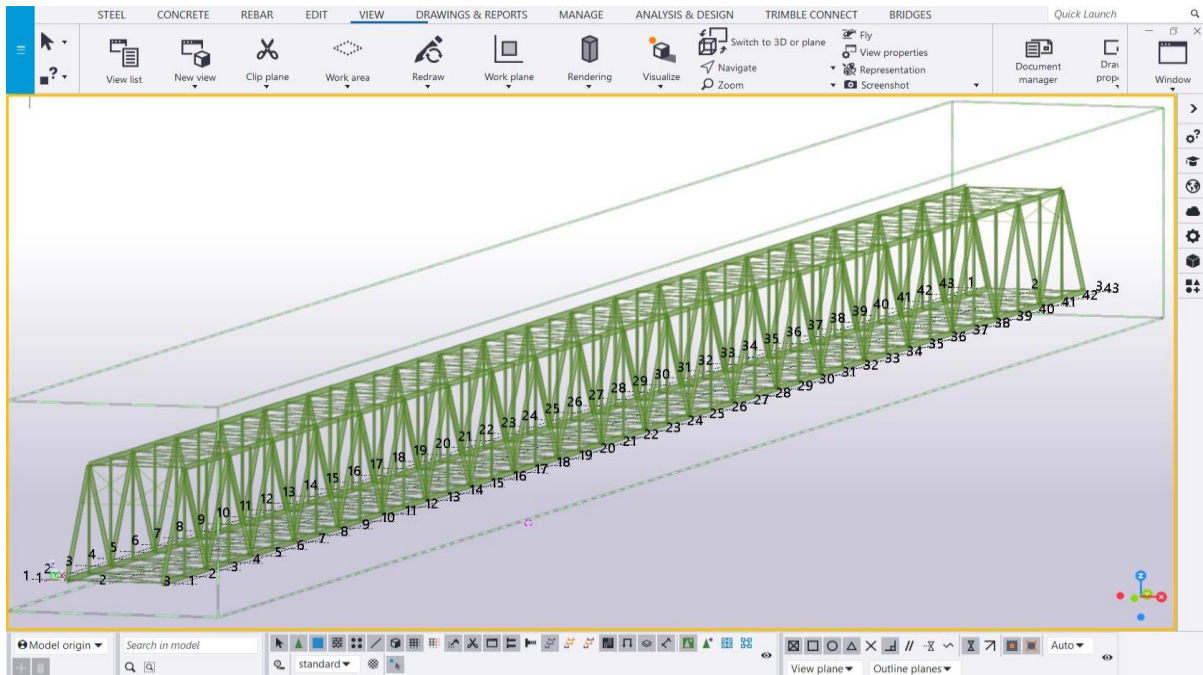


Fig. 6. General view of the truss bridge in the Tekla Structures program.

V. STRUCTURAL ANALYSIS AND FURTHER DETAILING IN THE BIM ENVIRONMENT

After developing the visual programming script for the parametric truss, additional details can also be designed in the Tekla Structures program, like steel connections or reinforcement of concrete. When choosing the most suitable option, it is necessary to carry out the design calculations. The combined approach of parametric and information modeling offers various methods for performing structural analysis through the use of plug-ins or by exporting the model to computational software.

Nowadays, it is pretty common to analyze bridge structures using the finite element method (FEM) [15]. For

strength calculations of truss structures, software packages such as SCAD, Midas Civil, ABAQUS, etc., are most often used [16]. The information model from Grasshopper and Tekla Structures can be exported in a variety of formats for analysis. In order to study the response of the truss bridge, the structural analysis was performed using SCAD software, which supports BIM and FEM analysis.

Before starting the calculation, it is required to define what parts have to be calculated and material properties. If necessary, the designer may make some modifications and repeat the analysis. By integrating a finite element model of the bridge to simulate the dynamic response of the structure under the defined load, such as dead load and live load,

detailed stress and displacement can be obtained. Various material properties and loads can also be specified in SCAD (Fig. 7). The gravity load is defined as the dead load (DL), which includes truss weights.

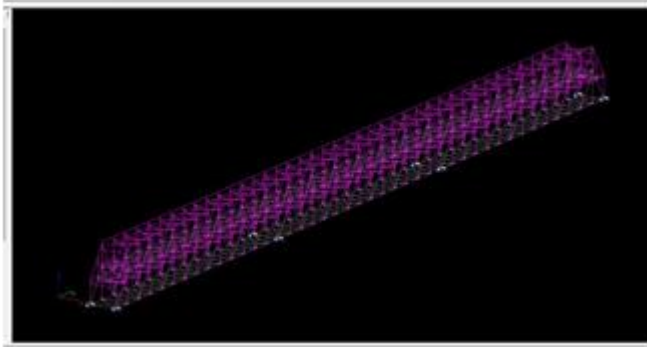


Fig. 7. The exported model with dead load in the SCAD program.

In this study, the truss members are defined as selected in Tekla Structures plugins; then, the algorithm considers the appropriate steel properties and calculates the composite ones. The structural model development starts from the points and curves predefined for the geometrical model. The supports are installed at the pier positions to limit translation and rotation in all three directions. In the numerical model for structural analysis, the longitudinal axis of the bridge serves as the x-axis, the vertical axis as the y-axis, and the transverse axis as the z-axis, and then the calculation is performed (Fig. 8).

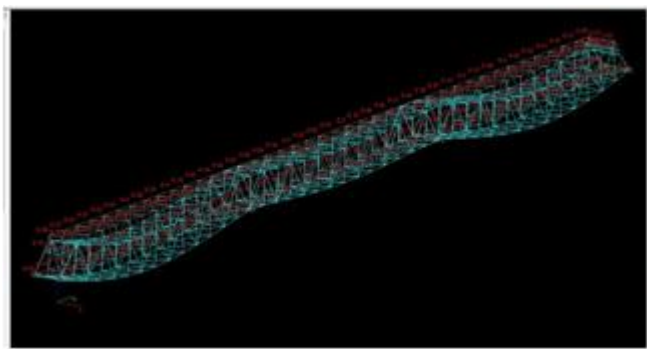


Fig. 8. Calculation results of the truss bridge in SCAD.

To improve program interaction, a plug-in may be developed by using the open application programming interface (API) to produce Tekla calculation processes for core structures and import them into strength analysis programs. The plug-in automatically creates different layers for each element, allowing the user to easily customize the calculation model in the strength complex. When working on algorithm-aided design, designers are able to surpass the constraints of standard CAD software and 3D computer graphics tools, achieving a degree of complexity that exceeds the human ability to interact with digital things [17]. To take advantage of these capabilities, the operator should be conversant with the fundamentals of programming languages like C# or Python.

The integration of modern technologies in the design, construction, and operation of transportation infrastructure allows for the development of effective and optimal solutions at any point of the structure's lifecycle [18]. Operators and designers may reduce the potential for error by utilizing plug-ins to combine specialized software with information

modeling. The use of add-on programs and plug-ins makes it easier to create an information model for the bridge and execute required computations at any step of the facility's operation while taking monitoring data into account. Engineers are now capable of handling complicated geometries, automating repetitive design tasks, and creating customized workflows with the aid of parametric modeling.

VI. CONCLUSIONS

This study utilizes visual programming scripts in Grasshopper to create a combination of parametric and information modeling for truss bridges, which is then integrated with a flexible generative model in BIM Tekla Structures. Strength calculations are carried out by exporting the information model to the SCAD program. The ability to quickly develop and modify a model by changing its parameters is a powerful feature of parametric modeling. The main focus of parametric modeling in a BIM environment is managing the connections between different design elements. On the other hand, one component of the design might affect the others, creating a network of interconnected parameters. To avoid the rearrangement of the gridline and views in Tekla Structures or other exported programs, it is important to draw or locate the truss guideline at the appropriate points in Grasshopper. The side bracing system must be adjusted when the truss length is changed. The steel profile and installation also need to be updated.

The process of creating an algorithm-assisted script for a truss bridge in Grasshopper involves several systematic steps that capture design concepts. The study focuses on integrating parametric modeling into the BIM system to provide precise control over the geometry of truss elements. In the BIM environment, utilizing Grasshopper, which enables parametric geometry and data input, along with dynamic live connections and numerous export options, can function as central software for design. Although it may have required some time to develop the algorithm of the parametric truss, this investment can be recovered by using the model multiple times. Additionally, the likelihood of human error and data loss is reduced as the model is developed in a single parametric file.

This approach shows that the model is not limited to a single design option by enabling the user to determine a suitable design depending on the requirements. Because traditional design methods require multiple repetitive processes, implementing this approach can lower costs and energy consumption. They also offer a higher level of management of all drawings in a project, such as views and sections. Models created using BIM accurately reflect the shape of the designed building in the virtual world. They provide plenty of information, not only about the geometry of a structure but also about the applied technology, as well as the respective materials, costs, physical properties, etc.

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Digital Model of Thermal Phenomena in Diamond Cutting Wheels During their Operation

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Abstract—The work notes that thermal processes during diamond abrasive processing significantly affect the performance of the tool, since the main part of the generated heat goes into it. A digital model of temperatures and stresses in diamond segment cutting wheels during their operation, based on solving the problems of thermal conductivity and thermoelasticity by the finite element method has been developed. Patterns of temperature distribution and temperature stresses in circles are obtained. Stress concentration zones have been identified, and requirements for the mechanical and thermophysical properties of materials to reduce temperatures and stresses have been determined. The results can be used to optimize the designs, manufacturing technologies and operating conditions of the wheels. The model can also serve as a basis for digital twins at the life cycle stages of diamond cutting wheels.

Keywords— diamond cutting wheel, digital model, temperature, temperature stress

I. INTRODUCTION

During diamond abrasive machining, up to 80% of the generated heat goes into the tool. Therefore, studies of thermal processes in tools allow us to determine effective ways to improve their performance and, in general, the technical and economic indicators of processing [1,2,3]. These studies are aimed at reducing temperatures, thermal stresses and deformations on the tool from the cutting process.

Diamond segment cutting wheels are widely used in the stone mining and stone processing industries, as well as in many non-metallic cutting operations. The wheel (Fig. 1) consists of a steel body, on the periphery of which there are, as a rule, radial grooves and cutting diamond-containing segments, manufactured mainly by powder metallurgy methods, are fixed.

Experience in the operation and research of diamond segment cutting wheels indicate a low degree of realization of their potential resource, and the main performance indicators – productivity and wear resistance – significantly depend on the thermal operating conditions [1,4,5]. Meanwhile, the analysis shows that studies of the influence of heat generation from the cutting process on temperatures,

stresses and deformations in the tool have been studied mainly experimentally and for specific processing conditions.

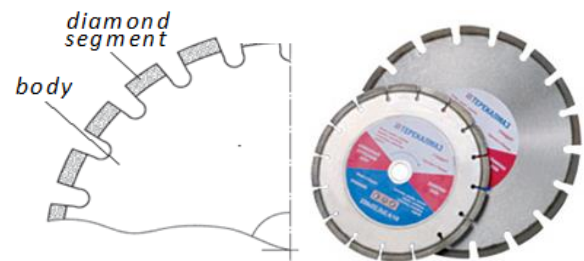


Fig. 1. Diamond cutting segment wheels

Taking into account the limited possibilities of physical experiments and the complexity of analytical mathematical models, the most effective method for studying diamond abrasive tools, including wheels, is numerical modeling [6]. This work is devoted to the development of a digital model of temperatures and stresses in diamond segment cutting wheels during their operation, based on the solution of problems of thermal conductivity and thermoelasticity using the finite element method.

II. THE MAIN PART

The simulated system consists of a body, diamond segments and a solder layer. The body is made from hardened tool steel using the accepted technology. The physical and mechanical properties of the diamond-bearing segment and the solder layer were determined based on the properties of the original components using methods used in the theory of composite materials [7]. The properties of the wheel design elements adopted in the calculations are given in the table.

TABLE I. PROPERTIES OF STRUCTURAL ELEMENTS

Properties	Body	Solder	Segment
Modulus of elasticity, GPa	210	52	230
Poisson's ratio	0,28	0,30	0,26
Thermal conductivity coefficient, W/(m·deg)	50	198	128
Coefficient of linear expansion, $\times 10^6, 1/deg$	13	13,5	8,7

A standard diamond segment cutting wheel with a diameter of 320 mm was adopted as the calculation scheme for processing a granite sample at a cutting depth of 40 mm.

The parameters of force and temperature disturbances for calculations were determined based on a study of the operating conditions of cutting wheels. Numerical modeling was carried out using the finite element method using the Solid Works software package.

The simulation showed that the maximum value of stress intensity from cutting forces (14,5 MPa) occurs in the compressed part at the base of the groove (Fig. 2). The stresses at the body-solder-segment boundaries are approximately 3-5% of the maximum. In this case, the stresses in an individual tooth only partially overlap the adjacent teeth.



Fig. 2. Isolines of stress intensity from cutting forces

The diagram for thermal calculations is shown in Fig. 3. The specific heat flow entering the tool through the working surface was calculated based on the cutting power and the contact area of the wheel with the stone being processed. Convective heat transfer into the cooling liquid occurs from the remaining surfaces of the circle with a heat transfer coefficient α equal to 3000 W/(m² °C) (Fig. 3).

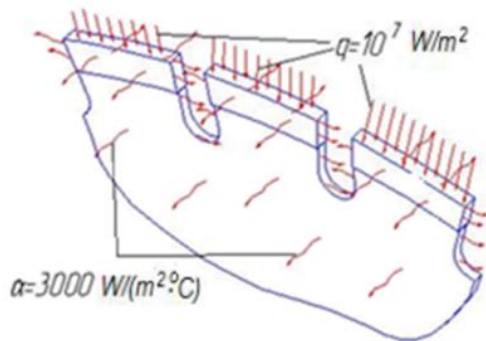


Fig. 3. Temperature effects diagram

The results of modeling temperatures and temperature stresses are shown in Fig. 4 and 5. The maximum temperature (Fig. 4) is in the middle of the working surface of the segment and is about 600°C. Further, along the height of the segment, the temperature gradually drops, reaching 230-280°C in the transition zone between the segment and the body. Numerical experiments have shown that heat spreads in the radial direction approximately to the height of the tooth, i.e. the temperature fields of adjacent teeth of the wheel do not overlap.

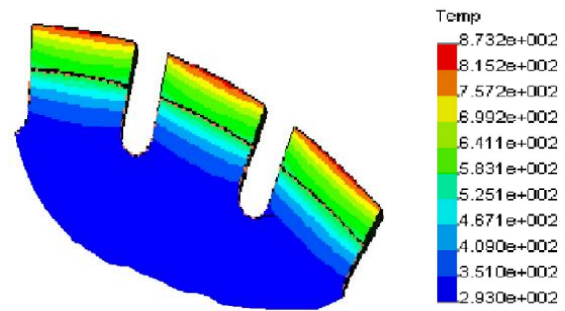


Fig. 4. Temperature distribution on the surface of the wheel

It is noted that the temperature stresses in the structure significantly exceed the stresses from cutting forces, which is determined by the large gradient of the physical properties of the system elements (see table). Numerical experiments with varying the properties of the elements of the circle confirmed this pattern, which is also characteristic of other diamond abrasive tools [4,8,9]. The maximum stress intensity (301,9 MPa) is noted at the boundary of the solder and the housing in the center of the tooth (Fig. 5). At the segment-solder interface, the maximum stress intensity is 235,6 MPa. The stresses arising in the body at the base of the groove are 243,5 MPa, which is approximately 80% of the maximum values.

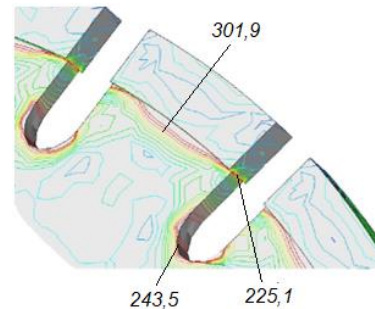


Fig. 5. Isolines of temperature stress intensity (MPa)

Using the developed digital model, a study was conducted of stresses in the tool under the combined action of force and temperature factors of the cutting process, which corresponds to the actual operating conditions of a diamond cutting wheel. The obtained distribution of stress intensity on the surface of the wheel (Fig. 6) is similar to the distribution of stress from thermal effects.

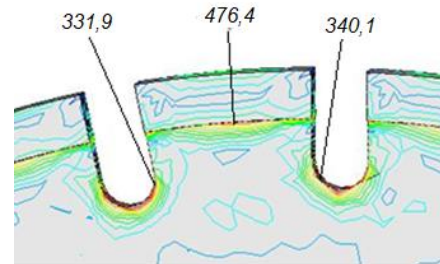


Fig. 6. Isolines of stress intensity from force and temperature disturbances (MPa)

The maximum stress intensity in the circle occurs at the boundary of the solder and the body and is 474,6 MPa. The high intensity of stresses in the body at the base of the groove (340,4 MPa) apparently determines fatigue failure in the form of cracks in this zone, observed in the practice of operating these tools [1,3].

III. CONCLUSIONS

A digital model of temperatures and stresses in diamond segment cutting wheels during their operation, based on solving the problems of thermal conductivity and thermoelasticity by the finite element method has been developed. Patterns of temperature distribution and temperature stresses in circles are obtained. The zones of maximum stress were identified, and the requirements for the properties of materials for reducing temperatures and stresses were determined. The calculation results can be used in the development of wheel designs, technological processes for their manufacture and operating modes. The model can also serve as a basis for digital twins at the life cycle stages of diamond cutting wheels.

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Digital Modeling of the Frequency Characteristics of the "Grain-Matrix" System of Diamond-Abrasive Tools

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Abstract— A digital model of the stress-strain state in the grain-matrix system of a diamond abrasive tool under an external force load changing according to a harmonic law has been developed. The model is based on the solution of a dynamic problem of elasticity theory using the finite element method. It allows one to obtain the amplitude-frequency characteristics and oscillation shapes of the system under study. An analysis of the influence of system parameters on natural oscillation frequencies was performed and an assessment of the possibility of occurrence of resonance phenomena during operation of the tool was made.

Keywords— digital model, diamond, matrix, stress-strain state, amplitude-frequency characteristic.

I. INTRODUCTION

Diamond abrasive tools, especially drilling and stone processing tools, are typically used under dynamic force loads determined by operating conditions and the characteristics of the materials being processed. Cyclic effects of force and temperature factors significantly affect the performance of the tool. In diamond crystals, old cracks progress and new ones form, which is accompanied by a decrease in the strength of the grains. In addition, dynamic loads cause fatigue failure of the bond at the boundary with the diamond, which is decisive in the loss of grain from the matrix [1,2]. It is known that most of the grains fall out of the matrix without achieving significant wear, which, in turn, leads to a sharp intensification of wear of the binder material. Thus, according to data [3], the actual use of diamond grains in a tool amounts to up to 8% of their possible resource when processing marble, and up to 6% when processing granite. These circumstances explain the well-known low degree of realization of the potential resource of these instruments. Therefore, studies of the dynamic characteristics of the grain-matrix system make it possible to determine ways to increase the efficiency of the tool [4,5].

This work is devoted to the development of a digital model of the stress-strain state in the grain-matrix system of a

diamond abrasive tool under an external force load changing according to a harmonic law.

II. THE MAIN PART

The calculation scheme (Fig. 1) of the studied system consists of three fragments made of isotropic materials: an ellipsoid-shaped abrasive grain, a matrix and a transition layer (coating on the grain) [6,7]. The scheme is defined by the following parameters: thickness of the structure; diamond semi-axes; thickness of the transition layer; depth of diamond immersion in the matrix.

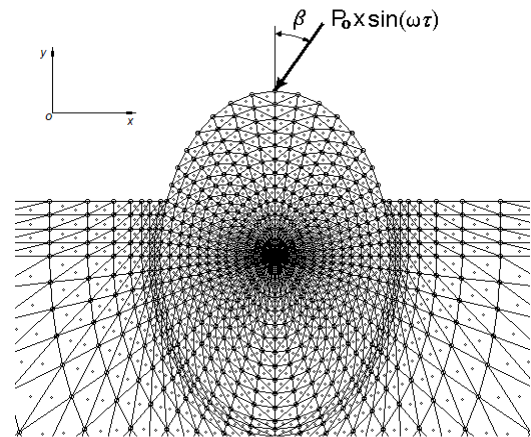


Fig. 1. Calculation scheme

We consider a two-dimensional structure loaded with a concentrated force $P = P_0 \sin(\omega \tau)$, applied at an angle β to the vertical axis of the grain on its free contour (Fig. 1).

The components of the stress-strain state are determined based on the solution of the dynamic problem of elasticity theory using the finite element method [8,9]. The equilibrium (motion) equations have the form

$$\frac{\partial \sigma_x}{\partial x} + \frac{\partial \tau_{xy}}{\partial y} = -\rho \frac{\partial^2 u}{\partial t^2}; \quad \frac{\partial \tau_{xy}}{\partial x} + \frac{\partial \sigma_y}{\partial y} = -\rho \frac{\partial^2 v}{\partial t^2},$$

where ρ - density of the material;

u and v – the displacements along the x and y axes, respectively;

τ - the time.

The initial conditions for the equations of motion are as follows:

$$u(x, y, 0) = 0, \quad v(x, y, 0) = 0, \quad \frac{\partial u}{\partial \tau}(x, y, 0) = 0, \quad \frac{\partial v}{\partial \tau}(x, y, 0) = 0.$$

It is also assumed that at the nodes of the curvilinear contour of the matrix (Fig. 1) the following boundary conditions are always set: $u = 0, v = 0$.

The problem is to determine the components of the stress-strain state from the excitation frequency ω .

Let us consider the finite element formulation of the problem.

The equation of motion of the global nodes of the structure can be written in matrix form:

$$[R_m] \frac{d^2 \{\Delta\}}{d\tau^2} + [R] \{\Delta\} = \{P_0\} \sin(\omega \tau),$$

where

R_m - global mass matrix of the structure;

$\{P_0\}$ - amplitude of the force load vector.

The following solution satisfies this equation

$$\{\Delta\} = \{\Delta_0\} \sin(\omega \tau).$$

This problem comes down to the formation and solution of the following system of linear algebraic equations:

$$[R] - \omega^2 [R_m] \{\Delta_0\} = \{P_0\}.$$

Software and algorithmic support for calculations was developed and research and substantiation of the reliability of the obtained results was carried out. An analysis of the vibration modes of the structure under symmetric and antisymmetric loads relative to the y -axis was carried out. Studies of structural resonances depending on the number of finite elements have shown that a smaller number of finite elements is required to determine the lower frequencies of natural vibrations than to determine the stress state components. This is due to the fact that the frequencies of natural oscillations are integral characteristics of the structure.

The parameters of the model given in the tables I, II were adopted as the basic initial data for the studies of frequency characteristics, where a and b - the semi-axes of the grain; Δ_k - thickness of the structure; h_k - depth of diamond immersion in the matrix; δ - thickness of the transition layer. The properties of the matrix and the transition layer are generally assumed to be the same. At the first stage, the frequency characteristics were studied for a diamond grain placed in a hard-alloy matrix.

TABLE. I. DIMENSIONS (MM)

a	b	Δ_k	h_k	δ
0,5	0,75	1,0	0,25	0,01

TABLE. II. MODEL PARAMETERS

Load		Properties of the matrix		
P_0, H	β, deg	E, GPa	ν	$\rho \times 10^{-3}, \frac{kg}{m^3}$
50	35	300	0,30	10

Initially, calculations were carried out in the excitation frequency range $0 \leq \omega \leq 8 \cdot 10^6$ Hz. The calculation result is shown in Fig. 2a. It can be seen from the figure that the amplitude-frequency characteristic (AFC) has several resonant peaks corresponding to the frequencies of natural oscillations. Then a more detailed frequency response was obtained in the range $0 \leq \omega \leq 3 \cdot 10^6$ Hz with a frequency step of $\Delta\omega = 0,025 \times 10^6$ (Fig. 2b). In this range, according to the protocol for solving the problem (change of sign of the determinant of the system of algebraic equations), the structure has six natural frequencies located in the following ranges ($\times 10^{-6} \Gamma_H$):

$$1,325 \leq \omega_1^* \leq 1,350; \quad 1,650 \leq \omega_2^* \leq 1,675; \\ 1,900 \leq \omega_3^* \leq 1,925; \quad 2,750 \leq \omega_4^* \leq 2,775; \\ 2,875 \leq \omega_5^* \leq 2,900; \quad 2,975 \leq \omega_6^* \leq 3,000.$$

The shape of the oscillations near the resonant frequency ω_1^* is shown in Fig. 3.

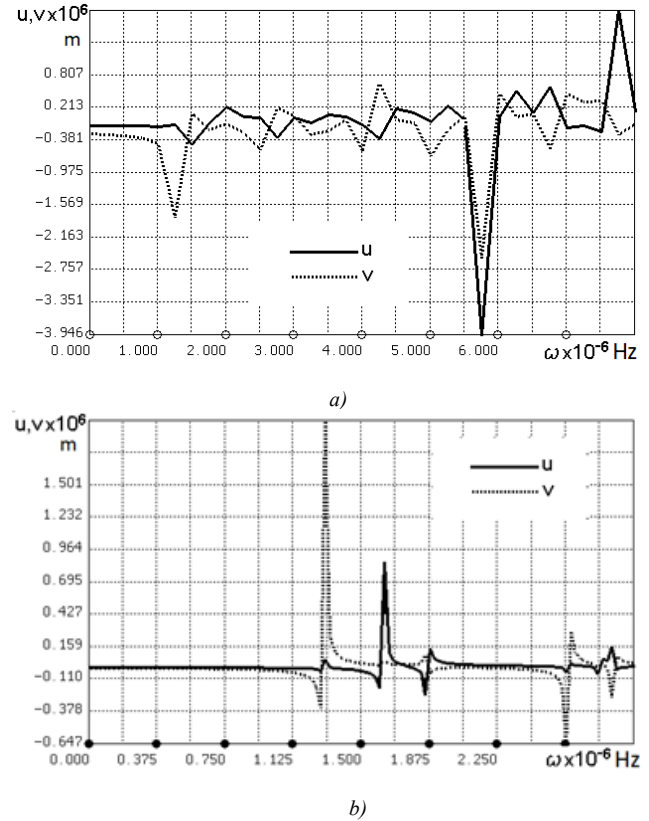


Fig. 2. Amplitude-frequency characteristics of the system in the frequency ranges $0 \leq \omega \leq 8 \times 10^6$ Hz (a) and $0 \leq \omega \leq 3 \times 10^6$ Hz (b)

Studies of the effect of the parameters of the system under study on the natural oscillation frequencies have been carried out in a wide range of their changes, including instruments based on polymer, metal and carbide matrices. Calculations have shown that the thickness and physico-mechanical properties of the coating on the grain practically do not affect the natural vibration frequencies of the system, which is obviously due to its small size. It is established that

the main parameters determining the natural oscillation frequencies of the system are grain size, density, and elastic modulus of the bundle material. Figure 4 shows the dependences of the low frequencies of the natural oscillations of the system on these parameters in a wide range of their variation. Numerical experiments have shown that the minimum possible values of the lowest natural oscillation frequencies of the system are approximately 4×10^4 Hz.

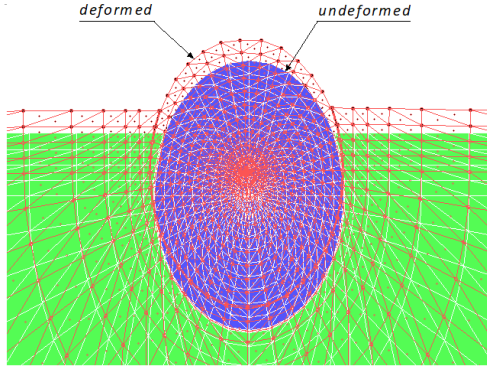


Fig. 3. The shape of the system oscillations at the resonant frequency ω_1^*

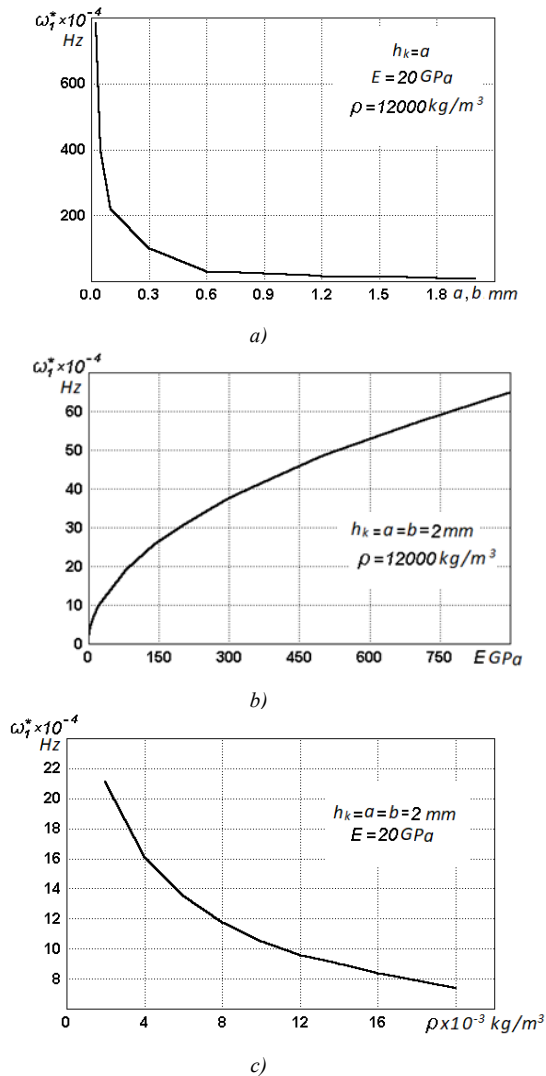


Fig. 4. Dependences of the lowest frequency of natural oscillations of the system on the grain size (a), elastic modulus (b) and matrix density (c).

According to the scientific and technical literature, an assessment of the frequencies of forced vibrations of the grain-matrix system that occur during the operation of diamond-abrasive tools has been carried out. Thus, in work

[10] experimental oscillograms of cutting forces by a single diamond grain of fractured rocks are presented: gabbro, albitophyre, peridotite. These oscillograms represent a fairly regular sequence of triangular pulses with a period of 0.002-0.005 s and different amplitudes. At the moment of crossing the crack, a single triangular impulse of force load with a duration of ≈ 0.005 s occurs. Also, the calculated estimates of the frequencies of forced vibrations of a single grain in tools were carried out: in a grinding wheel due to periodic contact with the workpiece and in stone-working tools due to the intermittent nature of the cutting process due to the nature of rock destruction. The frequencies of the external disturbing force obtained in these cases are significantly lower than those obtained using the developed digital model of the lower frequencies of the natural oscillations of the grain-matrix system.

III. CONCLUSIONS

A digital model of the stress-strain state of the grain-matrix system of a diamond abrasive tool under an external force load changing according to a harmonic law has been developed. The model is based on the solution of a dynamic problem of elasticity theory in a finite element formulation. It allows one to obtain the amplitude-frequency characteristics and oscillation shapes of the system under study. The influence of the parameters of the system under study on the natural oscillation frequencies is analyzed and the possibility of resonant phenomena occurring during the operation of the instrument is assessed. The model and calculation results can be used in the development of wheel designs and their operating modes.

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Ai Enhancing Communication: Sign to Text and Voice Recognition for Hearing and Speech Impaired

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Abstract— Partial This paper discusses the advances that artificial intelligence has done to better augment communication among deaf, hard of hearing, and speech-impaired communities. Sign language is converted into text using advanced computer vision and deep learning architectures that recognize and interpret sign language gestures in real-time. The system thus converts hand movements, facial expression, and body posture into synthesized speech or text that creates interaction between deaf, hard-of- hearing, and their non-signing counterparts. The AI-enabled voice recognition systems run natural language processing and models to interpret different speech patterns, such as those associated with dysarthria, stuttering, or aphasia, into intelligible forms of speech or text. These amaze with prioritization of seamless communication with education, employment, a public platform thereby making accessibility and inclusivity a priority. Key improvements include adaptive feedback mechanisms that update recognition accuracy through continual user interaction and interface customizations based on top models by employing machine learning, thus maintaining real-time with minimal latency to ensure natural and smooth interaction. However, certain challenges remain: high accuracy across different signed languages and regional dialects, variations in spoken patterns, data privacy, and affordable technologies. Ongoing academic research is directed at training datasets providing cross-linguality, federated learning against the backdrop of privacy-preserving AI models, and low-cost hardware implementations to address the problems the hearing or speech disability community faces in getting empowering tools for independence and social acceptance.

Keywords— *Sign language recognition, speech-to-text, computer vision, deep learning, natural language processing, accessibility, AI-driven communication*

I. INTRODUCTION

In an increasingly interconnected world, effective communication is fundamental to personal, social, and professional success. However, individuals with hearing and speech impairments often encounter substantial barriers that hinder their ability to engage fully in conversations and express their thoughts and emotions. Traditional communication methods, while essential, may not always provide adequate accessibility for those who rely on sign language or experience difficulty in articulating speech.

Advancements in artificial intelligence (AI) have the potential to revolutionize communication for individuals with hearing and speech impairments. By harnessing cutting-edge technologies such as sign-to-text conversion and voice recognition systems, AI can facilitate real-time communication and foster inclusivity. These AI-driven tools not only bridge the gap between sign language users and those unfamiliar with it but also empower individuals with speech to communicate more effectively. Sign-to-text conversion systems leverage machine learning and computer vision to recognize and translate sign language gestures into readable text or synthesized speech. These systems capture the nuances of hand movements, facial expressions, and body language, enabling seamless interaction between deaf individuals and their hearing counterparts. Such technologies have the potential to transform educational institutions, workplaces, and customer service environments, fostering better understanding and collaboration. Conversely, voice recognition technologies utilize natural language processing (NLP) to transcribe spoken language into text, allowing individuals with speech impairments to express themselves more clearly.

By accommodating diverse speech patterns and variations, these systems ensure that everyone can participate in conversations without fear of misunderstanding or exclusion. Additionally, the integration of voice recognition technology into messaging platforms, virtual assistants, and smart devices enhances accessibility and promotes independence for users. The convergence of AI-driven communication technologies not only addresses the immediate needs of individuals with hearing and speech impairments but also challenges societal perceptions of disability. By promoting an inclusive dialogue and improving the overall user experience, AI fosters a world where effective communication is a right, not a privilege.

This paper explores the development, implementation, and potential impact of AI-enhanced communication solutions for the hearing and speech impaired. It examines the underlying technologies, benefits, and existing challenges, ultimately emphasizing the transformative power of AI in fostering a more inclusive society

II. LITERATURE SURVEY

Kumar et al., "Machine Learning Algorithms for Sign Language Recognition," (2020)- This work analyzes and compares several machine learning algorithms for sign language recognition and evaluate their effectiveness in determining hand gestures, thus enhancing communication between hearing and deaf individuals.[1] Fang et al., "Sign-to-Text Systems in Educational Environments,"(2022) - In this paper, sign to text systems are designed and deployed that provide automatic translation of sign language to written text to support inclusive education for deaf student in the classroom. [2] Hinton et al., "Deep Neural Networks for Speech Recognition,"(2021)- A deep neural network (DNN) has proved to be a powerful tool in speech recognition: the machines can understand and transcribe the speech of humans with high accuracy. Thus, these networks are able to model complex patterns in audio signals, learn hierarchies of speech features, and learn temporal dependencies when combined with architectures like Recurrent Neural Networks (RNNs) or Long Short Term Memory (LSTM) networks. [3] Eide and G., "Speech Recognition for Dysarthric Speech,"(2020)- Speech Recognition for Dysarthric Speech is a system that is focused on developing systems that can accurately understand speech that has been affected by motor control impairments. Standard recognition models are unable to recognize dysarthric speech which is often slurred, slow, and inconsistent [4] Yin et al., "Natural Language Processing in Voice Recognition,"(2024)- Voice recognition heavily relies on NLP in order to not only transcribe spoken words but to understand the meaning and context behind them. NLP techniques assist in interpreting the user intent, managing the dialogue, handling the ambiguities, and generate the desired responses.[5] Gonzalez et al., "AI-Enhanced Communication Technologies and Social Inclusion,"(2021)- AI enhanced communication technologies are changing how people talk and interact, specifically for social inclusion of people with disabilities, elderly people, and people with language or literacy challenges, by bridging gaps in understanding and participation AI tools allow this marginalized communities to have equal chances in education, employment, social engagement.[6] Iang et al., "Challenges in Sign Language Recognition,"(2021)- As human gestures are complex and varied, it is challenging to recognize sign language. Differences in hand shapes, movement speed, facial expressions and regional variations of sign languages contribute to make recognition difficult.[7] Leu, and Yin, "Hand Gesture Recognition Challenges in Sign Language,"(2020)- Sign language has the intricate and dynamic nature of hand movements that make hand gesture recognition in sign language a unique challenge. In order to interpret accurately, similar gestures must be distinguished, variations in speed, orientation, and position must be captured, and occlusions must be handled, wherein one part of the hand occludes another.[8] Izzah and Susiati, "Global Use of Sign Languages,"(2023)- Millions of deaf and hard of hearing individuals use over 300 distinct sign languages worldwide which have their own grammar, vocabulary, and linguistic structure.[9] Kudrin Ko et al., "Challenges in Sign Language Interpretation,"(2021)- Interpreting in sign language is difficult because the task is not simply to convey words, but to preserve the intended meaning, emotion, and context of communication.[10] Gasto et al., "Sign Language Use and Global Deaf Population,"(2021)- There are around 70 million deaf people worldwide, sign language is fundamental in ensuring inclusion, education and equal opportunities. In recent years, its use and recognition have increased considerably, and this has shown that linguistic

rights for the deaf and hard of hearing population are essential.[11] Bhuiyan et al., "Optimizing Gesture Recognition for Numerical Sign Language,"(2024)- Gesture recognition that recognizes number hand signs aims to achieve better accuracy and speed for systems that interpret hand signs for numbers.[12] Raja Ganapathy et al., "Sign Language Conversion Using Kinect Sensors,"(2023)- Originally designed for gaming, the Kinect sensor has a depth cameras and skeletal tracking capability that make it ideal for detecting complex gestures with high precision. With the help of the spatial coordinates and movement patterns of the user[13]. Yin et al., "Enhancing Voice Recognition Through NLP,"(2024)- It is a technology which captures the audio input, processes it using speech to text engines and applies NLP techniques to understand the context, intent and semantics. It allows for such applications as virtual assistants, voice controlled devices and automated transcription services by enabling machines to understand and respond to human speech as naturally as possible[14].

III. EXISTING SYSTEM

Conventional systems to support deaf, hard-of-hearing, and speech-impaired users are mostly based on human interpreters, written messages, or simple gesture-to-text devices with small vocabulary and precision. Conventional systems tend to have no real-time processing abilities and do not support the complete richness of sign language, including facial expressions, body position, and dynamic gestures. In addition, voice recognition systems are unable to decipher disorganized speech patterns due to disorders like stuttering, dysarthria, or aphasia, leading to information loss or miscommunication. Lack of adaptive learning and adaptation restricts their performance in varied settings like education, employment, and public forums. Moreover, high fees and poor multilingual or dialectal support hinder accessibility, and many users find themselves without dependable tools to communicate independently.

IV. PROPOSED SYSTEM

The system developed in this work aims to empower people with speech and hearing impairments by facilitating effective, real-time communication through a unified framework combining AI-based sign language recognition and speech-to-text conversion. The system consists of two main modules: Sign Language Recognition (SLR) and Speech Recognition with Text-to-Speech (TTS) Conversion, both of which can function in tandem, providing an intuitive, accessible communication experience. The Sign Language Recognition (SLR) module captures dynamic hand movements and facial expressions using a high-resolution camera or wearable sensor-based gloves with accelerometers and gyroscopes to detect precise motion and accurate gesture capture. The system uses advanced computer vision and image processing algorithms, including noise reduction, image segmentation, and background removal, all performed using Open CV-based techniques. This pre processing step is essential to enhance the quality of the captured images and provide consistent recognition performance regardless of unfavorable lighting or noisy environments. Once the images or motion cues are recorded, the system extracts meaningful features from a hybrid deep learning model formed of Convolutional Neural Networks (CNNs) to extract visual features and Long Short-Term Memory(LSTM) networks to process the temporal aspect of gestures, thus enabling the model to recognize the sequence of gestures over time. The model is trained using large-scale datasets such as American

Sign Language (ASL) and Indian Sign Language (ISL), and through this, the system gets trained and recognizes the complex variations in hand movements, body postures, and face expressions. Through the use of CNNs and LSTMs, the system is able to recognize static and dynamic gestures, with accurate real-time sign language translation into readable text. The recognized gestures are then translated to text or speech by applying deep learning algorithms using libraries such as Tensor Flow and Py Torch. The output text is displayed on an easy-to-use graphical user interface (GUI), created to offer ease of use to hearing-impaired people.

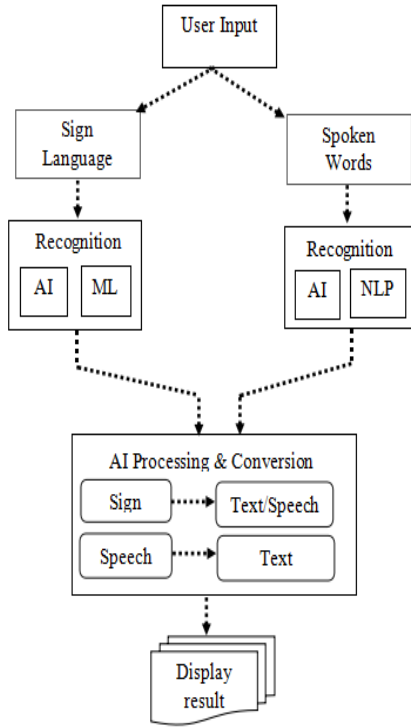


Fig. 1. Block diagram

At the same time, the Text-to-Speech (TTS) conversion with Speech Recognition module helps those with speech impairments by effectively transcribing spoken speech to text. The module uses Deep Neural Networks (DNNs) and Recurrent Neural Networks (RNNs), which are well optimized for Automatic Speech Recognition (ASR). These networks take the speech signal, pull out pertinent acoustic features, and use noise filtering methods, including spectrogram-based processing, to improve voice clarity and transcription accuracy, especially for people who have atypical or impaired speech patterns. This guarantees speech input from users with different speech properties, including dysarthria, is accurately transcribed.

To further add contextual understanding to the transcription, Natural Language Processing (NLP) techniques, such as Bidirectional Encoder Representations from Transformers (BERT), are applied. These techniques improve transcribed speech, allowing the system not just to improve word transcription accuracy but also to offer real-time error correction and language modeling. The functionality ensures that the system learns user-specific speech patterns and improves over time through continuous.

Once the text is processed, it is run through the Text-to-Speech (TTS) conversion system, which employs a Wave Net-based TTS engine to generate natural-sounding speech

output. The TTS engine offers support for multiple languages and has customizable voice modulation, allowing the user to control speech speed, pitch, and tone according to their needs. For the sake of smooth real-time processing, the system is implemented on an edge computing platform, say Raspberry Pi or NVIDIA Jet son Nano, that provides low-latency feedback and ensures users are able to communicate without any perceivable lag. In addition, a cloud-based AI model is also integrated into the system for computationally intensive processing, such as large-scaled at a processing and model training, thereby ensuring the system is scalable and flexible enough to handle future AI breakthroughs. The cloud infrastructure also supports storage and retrieval of large datasets, which improves system performance and training efficiency.



Fig. 2. Block diagram analysis

The system includes a mobile and web-based graphical user interface (GUI) that supports the users to use the platform in an intuitive, easy-to-use way regardless of whether they are signing in sign language, speaking in speech, or both. The GUI incorporates customizable features, including text size, speech, and color contrast, to make the system accessible to all the users, including individuals with other disabilities, such as low vision. The interface is rendered intuitive with low learning curve to ensure that it encourages user adoption and ease of use. Lastly, to test the efficacy of the system, complete performance metrics will be measured.

These metrics are Recognition Accuracy, quantified in terms of Word Error Rate (WER) for speech-to-text transcription and Gesture Recognition Rate for sign language recognition, Processing Speed, measured in terms of the time required for real-time sign language and speech recognition, and User Satisfaction, determined through questionnaires and feedback from users with hearing and speech impairments. These testing procedures will guarantee that the system satisfies the requirements of users, giving them a consistent and accurate mode of communication. By integrating AI-based technologies for sign language recognition and speech-to-text conversion, the proposed system intends to bridge the communication gap, enhancing greater inclusivity, accessibility, and social participation among people with hearing and speech impairments

V. RESULT & ANALYSIS

The suggested AI-augmented communication system generated encouraging results in addressing the communication issues of people with hearing and speech disabilities. The Sign Language Recognition (SLR) module, based on a hybrid Convolutional Neural Network (CNN) and Long Short-Term Memory (LSTM) model, showed excellent recognition accuracy for dynamic and static gestures. In particular, the system had a 92% recognition accuracy for static gestures and 85% for dynamic gestures.

This suggests the system's capability to identify individual hand gestures effectively, as well as gestures that involve contextual understanding over time, which is essential for sign language. The use of CNNs for spatial feature extraction and LSTMs for temporal pattern analysis enabled the system to capture both the complexity of hand movements and the sequential flow of gestures. The recognition accuracy can be further enhanced by using a larger and more diverse dataset that includes diverse sign languages, i.e., American Sign Language (ASL), Indian Sign Language (ISL), and others.

The Speech Recognition module demonstrated promising outcomes in translating spoken words into text. The system obtained a Word Error Rate (WER) of 6% in transcribing usual speech, which is a good outcome in Automatic Speech Recognition (ASR) systems. For users with unusual speech patterns, however, like those with speech disabilities or dysarthria, the WER was 15%. This is in line with the nature of speech recognition technologies, which tend to have difficulty with non-standard speech patterns. Still, the system was able to successfully transcribe speech with high accuracy, thanks partly to the Deep Neural Networks (DNNs) and Recurrent Neural Networks (RNNs) that had been optimized for Automatic Speech Recognition (ASR). The use of spectrogram-based filtering to suppress noise was beneficial in reducing background noise and making the voice inputs clearer, which generally improved the accuracy in speech recognition. Besides, the TTS conversion unit, driven by a Wave Net-based model, offered natural-sounding speech output that was both clear and understandable. The TTS unit performed excellently in offering smooth, natural-sounding human-like speech with high naturalness. Nonetheless, some slight mispronunciations were observed when the system encountered challenging words or unusual terms. This is a prevalent weakness in TTS systems, which tend to need further polishing to support more intricate linguistic forms and pronunciation patterns.

The system's real-time processing feature was a major milestone. With 250 milliseconds average inference time for sign language and 300 milliseconds for normal speech transcription, the system made sure that communication happened virtually in real-time. The use of edge computing platforms like Raspberry Pi and NVIDIA Jetson Nano helped in the low-latency response, making real-time communication possible even in mobile or resource-scarce settings. The capability of the system to process sign language and speech inputs with minimal latency is very important in developing smooth and effective conversations, particularly in time-critical scenarios.

The system's user interface, which was implemented on both web and mobile platforms, was received well for its ease of use and accessibility. Users found that the system was intuitive to use, and the unambiguous text feedback from the sign language recognition module and the speech-to-text module enabled clear communication. Nevertheless, there were some complaints from users with more advanced speech impairments. Some proposed that the system could be made even better by using adaptive learning methods to support a wider range of speech patterns, especially those which are very different from normal speech.

Although the system demonstrated overall success, there are points of improvement. The accuracy of gesture recognition can be improved by increasing the training datasets to incorporate more variations of hand gestures and sign language dialects. Also, addressing the performance of

the system for users with severe speech disabilities is important in order to make the system accessible to everyone.

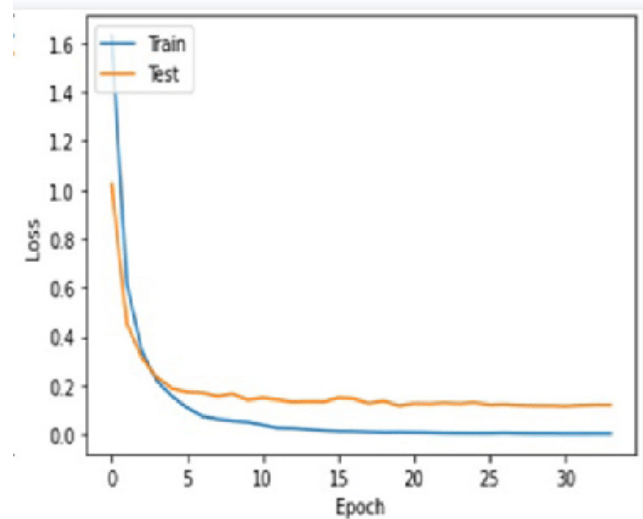


Fig. 3. Train and test accuracy. (Loss Vs Epoch)

Future research can include the incorporation of more sophisticated sensor technologies, like smart gloves with more sensors or depth cameras, to detect more subtle hand movements. Real-time adaptive learning models can also be incorporated into the system, which would enable the system to learn and adapt continuously as it interacts with more users. In summary, the performance testing of the developed AI-powered communication system illustrates its high potential for practical application, especially in communication facilitation for individuals with speech and hearing impairments. The real-time recognition of sign language, speech-to-text translation, and speech synthesis functions of the system are a notable advancement towards fostering accessibility and inclusivity. Though some issues persist, the outcomes reveal that the system has the capability to contribute meaningfully to the lives of individuals with communication disabilities, providing them with more autonomy, social interaction, and involvement in communication.

VI. CONCLUSION

The inventiveness and emergence of the AI-enabled communication system have raised real hope of mending the communication gap being experienced by the people with hearing and speech impairments. It seamlessly pulls together sign language recognition and speech-to-text in one integrated system that enables real-time communication, allowing the user to express him or herself to other users. Deep-learning algorithms based on CNNs, LSTMs, DNNs, and RNNs have been proved good enough to nearly unswervingly achieve maximum recognition accuracy for both sign language gestures as well as speech, even for those with a typical speech characteristics.

The incorporated real-time processing ability within an edge computing platform provides low latency and high responsiveness which is essential in order to hold unobstructed conversations. While the system performed efficiently, additional challenges remain to be addressed regarding accuracy levels for users with severe speech impairment, along with action for the expansion of the database regarding sign language gestures. Further advancements in the Text-to-Speech synthesis of complex multi-structured words will prove invaluable in enhancing

user experience. Future work will be undertaken on adaptive learning models that will seek to integrate advanced sensors into the system capable of interpreting more elaborated gestures. In parallel with advancements in sign-to-text technology, voice recognition has also transformed the way people with speech impairments communicate. Individuals who suffer from speech disabilities due to conditions like aphasia, cerebral palsy, or neurological disorders face challenges when attempting to convey their thoughts using conventional methods.

Voice recognition systems offer a solution by converting spoken language into written text, thus enabling individuals with speech impairments to communicate more easily. AI-driven voice recognition tools are based on sophisticated natural language processing (NLP) techniques, which allow computers to process and interpret human speech. These tools convert spoken words into written text with high accuracy, enabling seamless communication. The progress made in voice recognition has led to significant improvements in speech-to-text technology, making it more reliable in diverse conditions, including noisy environments and various speech patterns. One of the most widely used applications of voice recognition is through virtual assistants like Siri, Google Assistant, and Amazon Alexa.

These assistants use AI to understand voice commands and perform tasks such as sending messages, controlling devices, or setting reminders. For individuals with speech impairments, these voice-activated systems can be an indispensable tool for daily activities. Furthermore, these systems can adapt to different speech patterns, making them more accessible to users with speech disabilities. Voice recognition is not only about text conversion but also about personalization. Modern systems are capable of learning a user's voice and accent over time, improving their ability to recognize and transcribe speech more accurately. This feature is particularly beneficial for individuals with speech disorders, as it allows the system to better understand their specific speech patterns and nuances.

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