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Pedagogical Sciences

A Holistic Perception of the World Through Integrated Approaches at the Primary Level

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Abstract

One of the paramount challenges of contemporary education is enabling students to perceive the intrinsic connection between the classroom and the real world. This article explores the integrated approach to a holistic perception of the world at the primary education level (Grades V–VI), utilizing the interdisciplinary intersection of Science, "Our Georgia" (Social Studies), and Visual Arts. Drawing upon the real-world context of Jean Giono's narrative, *The Man Who Planted Trees*, the paper analyzes how the educational process transforms from delivering isolated facts into a vehicle for developing sustainable thinking and active citizenship. The study details the core principles of holistic teaching, including authenticity, inquiry-based learning, and constructivism in practice. Furthermore, the paper differentiates between Project-Based Learning (PBL) and the holistic worldview approach, offering practical recommendations and open-ended inquiry frameworks for educators. The study concludes that engaging primary students in localized ecological action fosters a profound sense of global citizenship and long-term socio-environmental responsibility.

Keywords

Integrated learning, holistic education, holistic worldview, interdisciplinarity, active citizenship, sustainable development, primary education.

A major challenge in contemporary education is helping students perceive the connection between the classroom and the real world—delivering information not in an abstract format, but through everyday real-life scenarios, and placing the emphasis not merely on memorizing facts, but on developing the skills essential for social and professional adaptation.

An integrated approach to a holistic perception of the world serves precisely to uncover this connection. Rather than offering isolated facts, it presents the world as a unified system.

In this approach, our starting point is a real, complex phenomenon that offers a unique opportunity to holistically investigate global-scale challenges at a local level, at the intersection of several disciplines. A prime example of this is Jean Giono's work, *The Man Who Planted Trees*. This real-life context allows the learning process to transcend the boundaries of a single subject and enables a complex analysis of the issue.

Key Question: How does the action of a single individual affect the well-being of the environment and society?

- **Subject: Science**

- ✓ **Target Concept:** Organism, Living Environment

- ✓ **Student Role:** Explorer / Researcher

- ✓ The student investigates: *How does a tree breathe? Why does soil not wash away where there are roots? Where does water come from in a dried-up riverbed?* The research process focuses on the interaction between the organism and the environment.

- **Subject: Our Georgia (Social Studies)**
 - ✓ **Target Concept:** Society
 - ✓ **Student Role:** Active Citizen
 - ✓ The emphasis is on shaping the student as an active citizen. In this process, the student transforms from a passive observer into a civic activist. The student critically evaluates the impact of an individual's purposeful initiative on the common social good. They analyze how a healthy environment creates new opportunities for societal development, strengthens social bonds, and raises the quality of life.
- **Subject: Visual Arts**
 - ✓ **Target Concept:** Fine and Applied Arts
 - ✓ **Student Role:** Creator and Visual Analyst
 - ✓ In this process, art serves as a means of perceiving and documenting environmental change. The student projects environmental change over time, capturing the transformation of the landscape. They paint the evolution of a landscape from a lifeless desert to a flourishing ecosystem. This is a path through which students translate their emotional attitude toward the environment into a visual language. Ultimately, they create a model or drawing of a future garden/park, visually expressing their civic stance.

This approach ensures that students understand that society and the environment are interdependent systems. Any positive action carried out at a local level—such as a greening campaign—is a real practice of civic participation aimed at global environmental outcomes.

To ensure that the holistic teaching process is effective, it must be grounded in the following principles:

1. Holism (Multifaceted Vision)

Show students the connection between nature and society. Ask the question: *How did the forest change the life of the village?* (Explore economic, social, and emotional aspects). Here, we must show children that nature helps humans physically survive.

- *Economic Aspect:* "How do you think, after Bouffier's forest grew and the water returned, why did people start coming back to the village? What were they able to do that was impossible before in the desert?" (e.g., planting gardens, raising livestock, selling crops). A forest means income and food. This easily brings the economic aspects to life.
- *Social Aspect:* Next, we explain to the children that a healthy environment improves relationships between people. When the village was a desert, people were angry and fled; when the forest appeared, people began to celebrate holidays together. *Why and how does a green environment bring people together?* Where nature thrives, society is happy and people help one another.
- *Emotional Aspect:* This is particularly sensitive, as it touches the child's inner feelings. We prompt students to reflect with the questions: *How do you feel when standing on a sun-scorched, dusty street? And how does your mood change when you listen to birds chirping in the shade of a tree? What did Bouffier feel when he looked at the forest he had grown?* Nature gives us peace, joy, and hope that our labor has meaning. When we approach the issue from these three angles, the student realizes that *forest-soil-water-human* is a single, interconnected life cycle.

This is holism in practice. Its relevance lies in the fact that in the modern world, teaching isolated, dry facts has lost its meaning—information is accessible to everyone. Our goal is to teach students not just isolated subject matters, but a way of life and sustainable thinking. When a child sees the connection between nature, economics, and social well-being, they acquire skills and

competencies vital for real-world survival and civic coexistence, rather than just knowledge required for a test grade.

Recommendations for Teachers to Activate Holistic and Integrated Learning

Principle	Recommendation (What to do)	Practical Example / Question
Authenticity	<p><i>Learning through the Window</i></p> <p>Connect the problem to the student's daily life.</p>	<p>Connect global-scale topics (such as the Amazon rainforests) to the local context. Ask the question: <i>What does our school yard need?</i></p>
Open-Ended Questions	<p>Pose questions that provoke discussion and reasoning.</p>	<p><i>How did a single person manage to turn a desert into a forest?</i></p> <p>or</p> <p><i>What will happen if we do not plant trees in our yard?</i></p>
Place-Based Learning	<p>Take the lesson outside, where the learning phenomenon actually exists.</p>	<p>Learning about an ecosystem in the school yard is more effective than in a book.</p> <p><i>(Why an ecosystem? It includes the soil the children investigate, the forest, and humans as part of this system).</i></p>
Inquiry & Discovery-Based Learning	<p><i>Experiential Learning</i></p> <p>Encourage students' curiosity so that they discover answers themselves through direct observation and discussion in the yard, rather than reading them in a textbook.</p>	<p>Start the lesson with a student-centered prompt:</p> <ul style="list-style-type: none"> • Stand first in the bright sun, then in the shade of a school yard tree, and compare the sensations. <i>Why do you think it is cooler in the shade of a tree than under an artificial umbrella?</i> • <i>Do you think the air in our school yard would change if we had 100 trees here?</i> • Look around: <i>Why do we hear birds chirping and insects buzzing only where there are trees and bushes?</i>
Constructivism in Practice	<p>Give students the opportunity to construct knowledge themselves through practical research.</p>	<p>Students take on the role of eco-landscape designers. Working in groups, they first inspect the school yard,</p>

Principle	Recommendation (What to do)	Practical Example / Question
		measure the space, observe the sunny and shady sides, and then jointly plan and create a greening model or a landscape sketch of the yard: <ul style="list-style-type: none"> • <i>Exactly where and what type of plants (trees, flowers, bushes) should be planted in the yard to restore the damaged ecosystem?</i> • <i>How can they create an ideal environment for birds and beneficial insects to return to the school yard?</i>

Integrating subjects through the model of a holistic perception of the world allows us to raise not only an informed student but also an active citizen who has the ability and desire to use their knowledge to improve the environment. When a student investigates the local environment and plans its revitalization—much like Elzéard Bouffier—they realize that environmental improvement is the duty of every citizen, not just state institutions.

By observing real-world phenomena (e.g., deforestation), the student analyzes the decision-making process. They learn that environmental responsibility is both collective and individual. The student recognizes their own role in creating the common good, which is the foundation of a democratic society.

A healthy environment is a fundamental human right. When taught through an integrated method, the student sees the connection between an ecosystem and a dignified human life. Caring for nature is perceived here as protecting the rights of others to clean air, water, and a healthy future. This method directly aligns with the concept of global citizenship, where solving a local problem is perceived as a contribution to planetary well-being.

While this type of teaching shares similarities with Project-Based Learning (PBL), Problem-Based Learning, and Inquiry-Based Learning, the main difference is that the holistic perception approach always maintains a global context and a mandatory interdisciplinary framework. The topic must be a real-world issue or phenomenon, and students must apply multiple perspectives to study it. A project focuses on solving a specific problem, whereas the holistic approach focuses on a deep, multifaceted understanding of the phenomenon.

Features	Project-Based Learning (PBL)	Holistic Perception of the World
Starting Point	A specific question or problem that needs solving. <i>(e.g., Concrete task: How do we plant 100 saplings in the school yard?)</i>	A real-world phenomenon, a complex issue. <i>(e.g., Climate change, migration, or bringing life back to a desert—how the environment changes humans and vice versa).</i>
Disciplinary Boundaries	Often confined within a single subject. <i>(e.g., Biology, focusing primarily on planting technology).</i>	Mandatory interdisciplinarity that dissolves subject barriers. <i>(Simultaneously learning the foundations of multiple disciplines: biology, history, art, and civics).</i>
Learning Process	Oriented toward creating a specific product. <i>(e.g., A green corner or a report on planting methods).</i>	Oriented toward a holistic, multifaceted comprehension of the phenomenon. <i>(Understanding how water, trees, humans, and the village economy are intertwined).</i>
Context	Can be hypothetical or purely academic. <i>(Students design a plan on paper that might not be implemented).</i>	Authenticity and contextuality—always related to real time and space. <i>(Going out into the yard, touching the soil, and researching a live community problem).</i>

For primary school students (Grades V–VI), Jean Giono's *The Man Who Planted Trees* remains one of the most powerful works. This story/animation about a single individual who turned a desert into a forest is ideal for this model of integrated learning, as it demonstrates how one citizen can transform an entire ecosystem.

Theoretical knowledge acquired within formal education and values acquired through informal means (care, civic responsibility, solidarity) merge into a single competence. The student realizes that planting a single sapling in the school yard is a small but powerful step in the fight against climate change. This is the path from a local initiative to global sustainability, which represents the ultimate mission of modern education.

This approach shatters the myth that *"I am small and cannot change anything."* Bouffier's story proves that an individual's consistency brings about revolutionary change. This directly enhances the child's self-esteem. Planting a flower in the school yard or initiating a community clean-up campaign is no longer a chore for them, but a demonstration of their own agency. The student learns patience—understanding that results do not appear instantly and that daily small steps are what matter.

Teaching through the principle of a holistic perception of the world fosters the formation of the student's value system. It urges students to look at the world not solely through personal interests,

but to care for the entire living environment. This is the path toward active citizenship, where a child internalizes their responsibility toward sustainable development and shared civic well-being.

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Жасөспірімдер арасында қимыл-қозғалыс белсенділігінің төмендеуі және оның алдын алу жолдары

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Аннотация

Бұл мақалада жасөспірімдер арасында қимыл-қозғалыс белсенділігінің төмендеу мәселесі және оның алдын алу жолдары қарастырылады. Қазіргі таңда жасөспірімдердің отырықшы өмір салтын ұстануы, гаджеттерге тәуелділігі және физикалық жүктеменің жетіспеушілігі денсаулыққа кері әсерін тигізуде. Мақалада қимыл-қозғалыс белсенділігінің төмендеу себептері талданып, оның алдын алудың тиімді жолдары – отбасылық тәрбие, мектептегі дене шынықтыру сабақтарының рөлі, салауатты өмір салтын насихаттау және қосымша спорт үйірмелерінің маңызы ғылыми тұрғыдан негізделеді.

Түйін сөздер: жасөспірім, қимыл-қозғалыс белсенділігі, гиподинамия, дене шынықтыру, салауатты өмір салты, алдын алу.

Қазіргі қоғамдағы жаһандану және технологиялық прогресс адам өмірінің барлық саласын қамтып отыр. Бұл үдеріс жасөспірімдер ортасына да терең еніп, олардың күнделікті тұрмыс-тіршілігіне айтарлықтай өзгерістер алып келді. Ақпараттық технологиялардың қарқынды дамуы, әлеуметтік желілер мен компьютерлік ойындардың танымалдылығы жасөспірімдердің бос уақытын ұйымдастыруда төңкеріс жасады. Дегенмен, бұл үдерістің кері әсері де бар: жасөспірімдер арасында қимыл-қозғалыс белсенділігінің төмендеуі денсаулық сақтау саласының өзекті мәселелерінің біріне айналды. Отырықшы өмір салты (гиподинамия) жас ұрпақтың физикалық дамуына ғана емес, психикалық және әлеуметтік денсаулығына да кері әсер етуде.

Қимыл-қозғалыс белсенділігі – ағзаның қалыпты өсуі, дамуы және жұмыс істеуі үшін қажетті негізгі факторлардың бірі. Дүниежүзілік денсаулық сақтау ұйымының (ДДҰ) деректері бойынша, 5 пен 19 жас аралығындағы балалар мен жасөспірімдер күніне кемінде 60 минут орташа және жоғары қарқынды физикалық белсенділікпен айналысуы керек. Алайда, зерттеулер көрсеткендей, әлем бойынша жасөспірімдердің басым бөлігі бұл норманы орындамайды. Бұл жағдай семіздік, жүрек-қан тамырлары аурулары, қант диабеті және тірек-қимыл аппаратының бұзылыстары сияқты денсаулық проблемаларының ерте жастан басталу қаупін арттырады. Ғылыми еңбектерде балалар мен жасөспірімдердің қимыл-қозғалыс белсенділігінің төмендеу себептері мен оның салдары кеңінен қарастырылған. Атап айтқанда, Н.М. Амосов, И.А. Аршавский сынды ғалымдар еңбектерінде қимыл-қозғалыс белсенділігінің ағзаның функционалдық мүмкіндіктерімен тығыз байланысы дәлелденсе, В.К. Бальсевич пен Л.И. Лубышева өз зерттеулерінде жас спортшылардың дайындық үдерісіндегі белсенділіктің маңызын атап көрсеткен. Педагогикалық тұрғыдан алғанда, П.Ф. Лесгафт жас ұрпақтың дене тәрбиесі жүйесінде қимыл-қозғалыс ойындары мен физикалық жаттығулардың тәрбиелік мәнін ерекше атаған. Бұл теориялық тұжырымдар жасөспірімдер арасында қимыл-қозғалыс белсенділігін арттырудың ғылыми негізін құрайды. Жасөспірімдердің қимыл-қозғалыс белсенділігінің төмендеуіне бірнеше факторлар әсер

етеді. Біріншіден, қазіргі білім беру жүйесіндегі оқу жүктемесінің жоғары болуы жасөспірімдердің көп уақытын отырып өткізуіне мәжбүрлейді. Екіншіден, цифрлық технологиялардың дамуы балалардың көшеде ойнап, белсенді қозғалуының орнына гаджеттер алдында отыруға уақыт бөлуіне алып келді. Үшіншіден, көптеген отбасыларда ата-аналардың жұмыспен қамтылуы және салауатты өмір салты туралы жеткілікті білімінің болмауы балалардың физикалық белсенділігіне жеткіліксіз көңіл бөлінуіне әкеп соғады. Төртіншіден, мектептердегі спорттық инфрақұрылымның жетіспеушілігі немесе қолжетімсіздігі де маңызды фактор болып табылады. Осы мәселелердің алдын алу және жасөспірімдердің қимыл-қозғалыс белсенділігін арттыру үшін кешенді және жүйелі тәсілдер қажет. Бұл бағыттағы жұмыстар бірнеше деңгейде жүзеге асырылуы тиіс:

Біріншіден, отбасылық тәрбиенің рөлі ерекше. Ата-аналар балаларына жеке үлгі көрсетіп, бірлескен спорттық іс-шараларға қатысуы керек. Демалыс күндері серуендеу, велосипед тебу, шаңғы тебу, жүзу сияқты отбасылық белсенді демалыс түрлерін ұйымдастыру жасөспірімдердің санасына қимыл-қозғалыстың маңыздылығын сіңірудің тиімді жолы болып табылады.

Екіншіден, мектептегі дене шынықтыру сабақтарының сапасы мен мазмұнын жақсарту қажет. Дәстүрлі спорт түрлерімен қатар, жасөспірімдерге қызықты әрі заманауи фитнес бағыттарын (кроссфит, йога, зумба, жаттығу залы) енгізу олардың сабаққа деген ынтасын арттырады. Дене шынықтыру пәнінің мұғалімі әр оқушының жеке қабілеті мен қызығушылығын ескере отырып, сараланған тәсіл қолдануы керек. Сабақ барысында спорттық ойындар мен жарыс элементтерін жиі пайдалану да оқушылардың белсенділігін арттыруға ықпал етеді.

Үшіншіден, мектептен тыс спорттық үйірмелер мен секциялардың жұмысын жандандыру қажет. Қосымша білім беру ұйымдары жасөспірімдердің спортқа деген қызығушылығын қанағаттандырып, олардың бос уақытын тиімді ұйымдастыруға мүмкіндік береді. Мемлекет тарапынан спорттық секцияларға қатысуды қолжетімді ету, материалдық-техникалық базаны жақсарту және білікті жаттықтырушылар даярлау мәселелеріне ерекше көңіл бөлінуі тиіс.

Төртіншіден, бұқаралық ақпарат құралдары мен әлеуметтік желілер арқылы салауатты өмір салтын насихаттау жұмыстарын жүйелі жүргізу маңызды. Спорт жұлдыздарының қатысуымен түсірілген бейнероликтер, челленджер, танымал блогерлердің салауатты өмір салты туралы контенттері жасөспірімдер арасында үлкен танымалдылыққа ие. Сонымен қатар, мектептерде салауатты өмір салтын насихаттайтын арнайы сабақтар мен іс-шаралар өткізу де тиімді әдістердің бірі.

Бесіншіден, қалалық жоспарлау кезінде жаяу жүргіншілер мен велосипедшілерге қолайлы инфрақұрылым құру, саябақтар мен спорт алаңдарының санын көбейту де қоғамның қимыл-қозғалыс белсенділігін арттыруға ықпал етеді. Балалар мен жасөспірімдердің қауіпсіз әрі қолжетімді жерде спортпен шұғылдану мүмкіндігінің болуы – олардың физикалық белсенділігінің маңызды шарты.

Қорыта айтқанда, жасөспірімдер арасында қимыл-қозғалыс белсенділігінің төмендеуі – күрделі әрі көп қырлы мәселе. Оның шешімі отбасының, мектептің, мемлекеттің және бүкіл қоғамның бірлескен күш-жігерін талап етеді. Мәселенің алдын алу – ауруды емдеуден гөрі оңай әрі тиімді. Сондықтан жас ұрпақтың денсаулығын сақтау және нығайту мақсатында қимыл-қозғалыс белсенділігін арттырудың жүйелі жолдарын әзірлеу және оны күнделікті тәжірибеге енгізу – бүгінгі күннің өзекті міндеті болып табылады. Жасөспірімдердің қимыл-қозғалыс белсенділігінің төмендеуінің алдын алуда дене шынықтыру сабақтарының маңызы ерекше. Өйткені мектеп – жасөспірімдердің басым бөлігі уақытын өткізетін және олардың физикалық дамуына жүйелі түрде әсер етуге мүмкіндігі бар негізгі әлеуметтік институт. Дене шынықтыру сабақтарының тиімділігін арттыру үшін оқытушылар заманауи педагогикалық

технологияларды қолдануы қажет. Спорттық-бағдарланған дене тәрбиесі технологиясы бойынша, әр оқушы өзіне ұнайтын спорт түрін таңдап, сонымен тереңірек айналысу мүмкіндігіне ие болады. Бұл тәсіл жасөспірімдердің дене шынықтыру сабағына деген қызығушылығын арттырып, олардың жүйелі түрде қатысуына ықпал етеді. Денсаулық сақтау технологияларын қолдану барысында оқушылардың жеке физиологиялық ерекшеліктері ескеріліп, жүктеме мөлшері дұрыс таңдалады. Бұл жасөспірімдердің дене шынықтырумен айналысу кезінде жарақат алу қаупін азайтып, сабақтан кейін оң әсер алуына мүмкіндік береді. Ақпараттық-коммуникациялық технологияларды қолдану да дене шынықтыру сабақтарының тартымдылығын арттырады. Мысалы, спорттық жарыстардың видеоталдауын жүргізу, жүрек соғысы жиілігін бақылайтын фитнес-браслеттерді қолдану, арнайы мобильді қосымшалар арқылы жаттығуларды орындау әдістемесін үйрену – осының бәрі жасөспірімдерге заманауи әрі қызықты. Сонымен қатар, мектепте спорттық клубтардың жұмысын жандандыру, түрлі спорттық секциялар мен үйірмелер ұйымдастыру, мектепішілік және мектепаралық спартакиадалар өткізу де оқушылардың қимыл-қозғалыс белсенділігін арттыруға зор ықпал етеді. Алайда дене шынықтыру сабақтары мен мектептегі спорттық іс-шаралар ғана жасөспірімдердің физикалық белсенділігін қамтамасыз ете алмайды. Тұрғылықты жердегі спорт алаңдары мен стадиондардың жай-күйі, спорттық үйірмелердің қолжетімділігі, қосымша сабақтардың құны да маңызды факторлар болып табылады. Сондықтан жергілікті атқарушы органдардың спорттық инфрақұрылымды дамытуға бағытталған саясаты жасөспірімдердің спортпен шұғылдануына қолайлы жағдай жасауы тиіс. Жасөспірімдердің қимыл-қозғалыс белсенділігін арттыруда мемлекеттік саясаттың рөлі зор. Қазақстан Республикасында «Дене шынықтыру және спорт туралы» Заң қабылданып, салауатты өмір салтын қалыптастыру мен дамытудың 2020-2025 жылдарға арналған мемлекеттік бағдарламасы бекітілген. Бұл құжаттарда халықтың барлық топтарының, соның ішінде жасөспірімдердің дене шынықтырумен жүйелі айналысуына жағдай жасау, спорттық инфрақұрылымды дамыту, бұқаралық спортты насихаттау сияқты маңызды бағыттар қарастырылған. Медициналық профилактика тұрғысынан алғанда, жасөспірімдер арасында қимыл-қозғалыс белсенділігінің төмендеуінің алдын алу үшін үнемі медициналық тексерулерден өткізіп, олардың физикалық даму көрсеткіштерін бақылау қажет. Мектеп дәрігерлері мен медбикелер денсаулығында ауытқулары бар балаларды анықтап, оларға арнайы жаттығулар кешенін ұсынып, ата-аналарына кеңес беруі керек. Сонымен қатар, дұрыс тамақтану мәдениетін қалыптастыру да жасөспірімдердің денсаулығын сақтаудың маңызды шарты болып табылады. Қимыл-қозғалыс белсенділігінің төмендеуінің алдын алуда психологиялық аспектіні де ескеру қажет. Жасөспірімдер көбінесе дене бітіміне, салмағына немесе физикалық дайындығының төмендігіне байланысты өздерін ұят сезініп, спортпен айналысудан бас тартады. Мұндай жағдайда мұғалімдер мен психологтардың қолдауы маңызды рөл атқарады. Жасөспірімдерге олардың физикалық кемшіліктері емес, спортпен айналысу барысындағы талпыныстары мен жетістіктері маңызды екенін түсіндіру керек. Топтық жаттығулар мен командалық спорт түрлері жасөспірімдердің әлеуметтенуіне, достарымен қарым-қатынасын нығайтуға және өзіне деген сенімділігін арттыруға көмектеседі. Қорытындылай келе, жасөспірімдер арасында қимыл-қозғалыс белсенділігінің төмендеуі өзекті әрі күрделі мәселе екені анық. Оның алдын алу үшін отбасы, мектеп, мемлекет және бүкіл қоғамның бірлескен күш-жігері қажет. Бұл бағыттағы жұмыстар жүйелі, әрі ғылыми негізделген болуы тиіс. Физикалық белсенділікті арттырудың тиімді жолдарын іздестіру, заманауи технологиялар мен әдістерді енгізу, спорттық инфрақұрылымды жақсарту және салауатты өмір салтын кеңінен насихаттау – осының бәрі жас ұрпақтың денсаулығын сақтап, олардың үйлесімді дамуына ықпал етеді. Жасөспірімдердің белсенді әрі салауатты өмір салты – ел болашағының кепілі екенін естен шығармауымыз қажет.

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Снижение двигательной активности среди подростков и пути его профилактики

Аннотация

В данной статье рассматривается проблема снижения двигательной активности среди подростков и пути ее профилактики. В настоящее время малоподвижный образ жизни подростков, зависимость от гаджетов и недостаток физических нагрузок оказывают негативное влияние на их здоровье. В статье анализируются причины снижения двигательной активности и научно обосновываются эффективные пути ее профилактики – роль семейного воспитания, значение уроков физической культуры в школе, пропаганда здорового образа жизни и важность дополнительных спортивных кружков.

Ключевые слова: подросток, двигательная активность, гиподинамия, физическая культура, здоровый образ жизни, профилактика.

Decrease in Physical Activity Among Adolescents and Ways to Prevent It

Abstract

This article examines the issue of decreased physical activity among adolescents and ways to prevent it. Currently, adolescents leading a sedentary lifestyle, dependence on gadgets, and lack of physical exercise are negatively affecting their health. The article analyzes the causes of decreased physical activity and scientifically substantiates effective ways to prevent it – the role of family education, physical education classes at school, promotion of a healthy lifestyle, and the importance of additional sports clubs.

Keywords: adolescent, physical activity, hypodynamia, physical education, healthy lifestyle, prevention.

БИОЛОГИЯ САБАҚТАРЫНДА ЖАСАНДЫ ИНТЕЛЛЕКТ АРҚЫЛЫ ПАЛЕОНТОЛОГИЯЛЫҚ ДЕРЕКТЕРДІ ВИЗУАЛИЗАЦИЯЛАУ ӘДІСТЕМЕСІ

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Аңдатпа

Палеонтологиялық материалдарды биология сабақтарында оқытудың инновациялық әдістемесін жасау шеңберінде жасанды интеллект технологияларының дидактикалық әлеуеті теориялық тұрғыдан негізделді. Оқушылардың сыни ойлауы мен зерттеушілік құзыреттіліктерін дамыту мақсатында генеративті мәтіндік және нейрожелілік графикалық платформалар арқылы палеобиологиялық нысандар туралы ғылыми гипотезаларды визуализациялау жолдары айқындалды. Промпт-инжиниринг әдісі мен нейрондық 3D-модельдеу процесі оқушылардың терминологиялық сауаттылығын арттыруға және деректерді верификациялау дағдыларын қалыптастыруға мүмкіндік беретін пәрменді құрал ретінде қарастырылады. Теориялық-методологиялық талдау нәтижесінде жаратылыстану білімі мен IT-технологиялар интеграциясын қамтамасыз ететін «сипаттама-промпт-визуализация» әдістемелік моделінің құрылымы айқындалды. Ұсынылған тұжырымдар мен әдістемелік тәсілдер биологиялық білім берудегі көрнекілік базасын заманауи цифрлық технологиялар арқылы кеңейтуге бағытталған.

Кілт сөздер: жасанды интеллект, палеонтология, биологияны оқыту, визуализация, промпт-инжиниринг, сыни ойлау, 3D-реконструкция.

Кіріспе

Тақырыптың өзектілігі. Қазіргі таңда білім беру жүйесін цифрлық трансформациялау және жасанды интеллект (ЖИ) технологияларын енгізу оқу процесін сапалы жаңа деңгейге көтерудің басты шарты болып табылады. Биология сабағындағы күрделі әрі абстрактілі тақырыптардың бірі — эволюциялық процесс және палеонтологиялық деректерді талдау. Оқушылар үшін миллиондаған жылдар бұрын өмір сүрген организмдерді тек дәстүрлі кескіндемелік суреттер арқылы елестету қиындық тудырады, бұл пәнге деген қызығушылықтың төмендеуіне әкелуі мүмкін.

Зерттеудің мақсаты. Биология сабақтарында жасанды интеллект құралдарын қолдана отырып, палеонтологиялық деректерді визуализациялаудың әдістемелік ерекшеліктерін айқындау және осы технологиялардың білім алушылардың пәндік құзыреттіліктерін қалыптастырудағы тиімділігін негіздеу.

Негізгі бөлім

1. Биологиядағы ЖИ технологияларының дидактикалық әлеуеті

Цифрлық трансформация биологияны, әсіресе палеонтология сияқты күрделі тақырыптарды оқыту әдістемесін жаңартуда. Зерттеулер көрсеткендей, жасанды интеллект (ЖИ) технологиялары биологиялық концепцияларды визуалды қабылдау деңгейін 40-50%-ға арттырады [1]. ЖИ палеонтологиялық деректерді оқушының танымдық деңгейіне сай интерактивті нысанға айналдырып, ғылыми болжам жасау және модельдеу дағдыларын қалыптастырады [2].

2. Визуализациялаудың инновациялық әдістері

Палеонтологиялық жәдігерлерді дидактикалық реконструкциялау және олардың филогенетикалық даму заңдылықтарын модельдеу қазіргі жаратылыстану-ғылыми білім берудің өзекті парадигмаларының бірі болып табылады. Дәстүрлі оқыту құралдарының статикалық сипаты геологиялық кезеңдердегі биоәртүрліліктің трансформациялық процестерін және морфологиялық бейімделу механизмдерін динамикада бейнелеуге қауқарсыз. Осы тұрғыдан алғанда, білім беру мазмұнына визуалды-конструктивті және когнитивті-визуалды тәсілдерді біріктіру оқушылардың эмпирикалық білімін теориялық-абстрактілі деңгейге көтерудің басты дидактикалық шартына айналуға тиіс. Бұл бағытта палеобиологиялық нысандардың құрылымдық-функциялық ерекшеліктерін сабақ үдерісінде модельдеу үшін келесі инновациялық технологиялық тәсілдердің әлеуеті жоғары:

2.1. Генеративті модельдеу және промпт-инжиниринг:

Grok, DALL-E 3 немесе Stable Diffusion платформалары арқылы оқушылар ғылыми сипаттамалар негізінде нысанның сыртқы келбетін қалпына келтіреді. Промпт құрастыру барысында «эпидермис құрылымы», «морфологиялық адаптация» терминдерін қолдану теориялық білімді практикада бекітеді [3]. Мысалы, динозаврлардың қауырсынды жамылғысы туралы гипотезаларды ЖИ арқылы визуализациялау оқушының сыни ойлауын дамытуға мүмкіндік береді [4].

Биология сабақтарында оқушыларға динозаврлардың сыртқы келбеті (мысалы, қауырсынды жамылғысы) туралы гипотезаларды ЖИ арқылы тексеру тапсырмасы беріледі. Оқушылар ғылыми сипаттамаларды жинақтап, промпт құрастырады. Промпт-инжиниринг әдісін практикалық қолданудың нәтижесі ретінде Дейноних (*Deinonychus antirrhopus*) динозаврының ғылыми-фотореалистік реконструкциясы 1-суретте көрсетілген.



Сурет 1 - Grok (X) жасанды интеллектісімен жасалған Дейнонихтің (*Deinonychus antirrhopus*) қауырсынды реконструкциясы (автормен құрастырылған)

2.2. Нейрондық 3D-реконструкциялау

Luma AI және Skybox AI құралдары 2D кескіндер мен қазба қалдықтарынан көлемді 3D модельдер жасауға мүмкіндік береді. Бұл әдіс нысанды 360 градус кеңістікте зерттеп, оның анатомиялық ерекшеліктерін егжей-тегжейлі талдауға жағдай жасайды [5].

3. Әдістемелік алгоритм және құзыреттіліктерді қалыптастыру

Биология сабағында ЖИ құралдарын қолданудың келесі кезеңдік алгоритмі ұсынылады:

- Дереккөздерді верификациялау: Академиялық негізде нысан сипаттамасын жинақтау.
- Визуалды гипотеза жасау: ЖИ көмегімен организмнің түрлі биологиялық нұсқаларын (түсі, бейімделуі) модельдеу.
- Рефлексия және салыстыру: ЖИ өнімін ғылыми атластармен салыстырып, қателерді анықтау [6].

Бұл тәсіл оқушылардың цифрлық және зерттеушілік құзыреттіліктерін дамытады. Тәжірибе бойынша, визуализацияланған материалдар ақпаратты есте сақтау көрсеткішін 75%-ға дейін арттырады [7; 8].

Зерттеу нәтижелері мен талқылау

Зерттеу барысында палеонтологиялық деректерді ЖИ арқылы визуализациялаудың әдістемелік моделі құрастырылып, келесідей тұжырымдар анықталды:

- Визуалды-дидактикалық модель: Grok, Midjourney, Luma AI платформаларының көмегімен «цифрлық реконструкция» концепциясының [1; 4] тиімділігі дәлелденді. Дейноних (*Deinonychus*) динозаврының қауырсынды жамылғысын модельдеу (2-сурет) статикалық кескіндерді динамикалық нысанға айналдырып, абстрактілі гипотезаларды қабылдау деңгейін арттырды.
- Промпт-инжиниринг: Сұраныстар дайындау процесі «биологиялық тілді қалыптастыру» принципімен [3] тікелей байланысты. Оқушылардың «dromaeosaurid», «morphological adaptation» сияқты терминдерді қолдануы терминологиялық базаның активті қолданысқа өтуін қамтамасыз етеді.
- Сыни ойлау және 3D-реконструкция: Luma AI және Meshy құралдары «кеңістіктік танымды» [5] жақсартады. ЖИ жіберген анатомиялық қателерді («галлюцинацияларды») ғылыми атластармен салыстыру — оқушыны ақпарат тұтынушыдан верификациялаушы сарапшы деңгейіне көтерудің тиімді жолы.

Қорытынды

Зерттеу нәтижелері ЖИ технологияларының палеонтологиялық деректерді визуализациялаудағы жоғары әдістемелік әлеуетін көрсетті. ЖИ платформалары оқу материалының көрнекілігін арттырып, оқушылардың цифрлық сауаттылығы мен кеңістіктік ойлауын дамытады. Промпт-инжиниринг терминологияны практикалық меңгеруге, ал өнімді верификациялау сыни ойлауды жаңа деңгейге көтеруге мүмкіндік береді. Ұсынылған әдістемелік модель биологиялық білім беруді жаңартудың және зерттеушілік құзыреттіліктерді қалыптастырудың маңызды факторы болып табылады.

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ИНТЕРАКТИВНЫЙ ТРЕНАЖЁР КАК ИНСТРУМЕНТ ФОРМИРОВАНИЯ ПЕДАГОГИЧЕСКИХ НАВЫКОВ БУДУЩИХ УЧИТЕЛЕЙ МАТЕМАТИКИ: РАЗРАБОТКА И ЭКСПЕРИМЕНТАЛЬНАЯ АПРОБАЦИЯ

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Аннотация

В статье представлены результаты разработки и экспериментальной апробации интерактивного тренажёра для формирования педагогических навыков будущих учителей математики. Тренажёр построен на нелинейной системе сценариев реальных школьных ситуаций с динамическими метриками и ориентирован на специфику казахстанской нормативно-правовой базы. Педагогический эксперимент с участием 35 студентов 3–4 курсов Кокшетауского университета им. Ш. Уалиханова подтвердил высокую эффективность тренажёра по трём группам критериев: когнитивным (прирост 55,1%, $r = 0,71$), деятельностным (43,5%, $r = 0,68$) и рефлексивным (36,2%, $r = 0,59$). Все эффекты статистически значимы ($p < 0,001$) и соответствуют большому размеру эффекта.

Ключевые слова: педагогический тренажёр, симуляционное обучение, будущие учителя математики, педагогическая самоэффективность, нелинейные сценарии, динамические метрики, казахстанское образование.

Abstract

The article presents the results of developing and experimentally testing an interactive simulator for forming pedagogical skills in future mathematics teachers. The simulator is based on a non-linear scenario system of real classroom situations with dynamic metrics, oriented toward the specifics of Kazakhstan's regulatory framework. A pedagogical experiment involving 35 students (3rd–4th year) at Sh. Ualikhanov Kokshetau University confirmed the simulator's high effectiveness across three criterion groups: cognitive (gain 55.1%, $r = 0.71$), activity-based (43.5%, $r = 0.68$), and reflective (36.2%, $r = 0.59$). All effects are statistically significant ($p < 0.001$) and correspond to large effect sizes.

Keywords: pedagogical simulator, simulation-based learning, future mathematics teachers, teaching self-efficacy, non-linear scenarios, dynamic metrics, Kazakhstan education.

Введение

Система педагогического образования Республики Казахстан переживает период активной трансформации. Обновлённые государственные стандарты и квалификационные требования к педагогическим работникам предъявляют высокие требования к профессиональной компетентности учителя математики, охватывающие предметную, методическую, коммуникативную и правовую составляющие [1; 2]. Вместе с тем практика показывает: между теоретической подготовкой выпускников педагогических специальностей и их реальной готовностью к профессиональной деятельности существует значительный разрыв.

С целью верификации данной проблемы нами был проведён опрос 70 молодых учителей математики Акмолинской области (стаж до 3 лет). Результаты показали, что 81% испытывают нехватку практических педагогических навыков, 78% — отсутствие безопасной тренировочной среды, 73% — разрыв между теоретической подготовкой и реальными требованиями школы. Данные результаты согласуются с выводами международных исследований в области педагогического образования [3; 4].

В качестве инструмента преодоления данного разрыва мировая педагогическая наука всё активнее обращается к симуляционным технологиям. Метаанализ Черниковой и соавторов [5], охвативший 145 эмпирических исследований, установил значительный эффект симуляционного обучения по сравнению с традиционными методами ($g = 0,85$). Вместе с тем существующие зарубежные системы не адаптированы к специфике казахстанской нормативно-правовой базы и реальных ситуаций казахстанской школы, что обусловило необходимость разработки оригинального отечественного инструмента.

Цель настоящей статьи — представить концептуальную модель, техническую реализацию и результаты экспериментальной апробации интерактивного тренажёра для формирования педагогических навыков будущих учителей математики.

Теоретическое обоснование модели тренажёра

Концептуальная модель разработанного тренажёра опирается на четыре теоретических основания. Теория поэтапного формирования умственных действий П.Я. Гальперина [6] обосновывает роль тренажёра как инструмента обеспечения пропущенного этапа материализованного педагогического действия — отработки профессионального решения во внешней форме с наблюдаемыми последствиями. Без данного этапа переход от теоретического знания к автоматизированному профессиональному навыку принципиально затруднён.

Концепция педагогической самооэффективности А. Бандуры [7] объясняет механизм влияния тренажёра на профессиональное развитие студента: успешное прохождение сложных сценариев формирует «опыт мастерства» — наиболее мощный источник самооэффективности, обеспечивающий рост профессиональной уверенности. Теория проблемного обучения М.И. Махмутова [8] обосновывает педагогическую ценность сценариев без единственно правильного ответа: когнитивное затруднение при выборе между конкурирующими профессиональными стратегиями является движущей силой подлинного профессионального обучения. Теория экспериментального обучения Д. Колба [9] определяет цикличность и возобновляемость опыта в тренажёре как условие его педагогической эффективности.

Архитектура и техническая реализация тренажёра

Разработанный тренажёр представляет собой веб-платформу, реализованную на технологическом стеке Django — PostgreSQL — Bootstrap. Данный выбор обусловлен необходимостью обеспечить: нелинейный механизм ветвления сценариев через граф состояний $G = (V, E)$; гибкую систему динамических метрик на основе JSONB-полей; административный интерфейс для управления содержимым без программирования; доступность с любого устройства через стандартный браузер.

Система сценариев тренажёра структурирована по четырём содержательным блокам: «Методика преподавания математики» (объяснение нового материала, работа с ошибками, дифференцированное обучение), «Управление классом и дисциплина» (реагирование на нарушения, конфликты, демотивированный класс), «Нормативно-правовые ситуации» (права участников образовательного процесса, оценивание, экстренные ситуации) и «Взаимодействие с родителями» (претензии, конфликты, информирование о проблемах ученика). Каждый сценарий содержит контекст, триггер, варианты ответов (от 2 до 10), коэффициенты изменения динамических метрик и указание на следующую сцену в соответствии со структурой графа.

Динамические метрики тренажёра отражают ключевые параметры педагогической ситуации: уровень понимания учебного материала учениками, уровень дисциплины в классе, мотивацию учащихся, временной ресурс урока и эмоциональную нагрузку учителя. Каждый выбор пользователя мгновенно изменяет значения метрик, создавая наглядную обратную связь о последствиях принятых педагогических решений. Нелинейность структуры обеспечивает индивидуальность сценарного пути каждого пользователя и формирует реальную ответственность за принимаемые решения.

Содержание сценариев разработано на основе двух эмпирических источников: опроса 70 молодых учителей математики Акмолинской области (выявление реальных профессиональных затруднений) и экспертных оценок опытных педагогов-математиков школ региона (верификация педагогической адекватности вариантов ответов и коэффициентов метрик). Нормативно-правовые сценарии основаны на актуальном законодательстве РК в сфере образования.

Методика педагогического эксперимента

Педагогический эксперимент проводился на базе Кокшетауского университета им. Ш. Уалиханова по схеме пре-тест/пост-тест ($O_1 \rightarrow X \rightarrow O_2$). В эксперименте участвовали 35 студентов 3–4 курсов педагогических специальностей (22 студентки, 13 студентов), освоивших теоретические курсы педагогики и методики преподавания математики, но не завершивших самостоятельную педагогическую практику. Все участники добровольно подписали информированное согласие; обработка данных осуществлялась с использованием анонимных кодов.

Диагностический инструментарий включал три измерительных инструмента. Для оценки когнитивных показателей применялся «Тест знания нормативно-правовой базы» (20 вопросов, 4 субшкалы, коэффициент надёжности альфа Кронбаха $\alpha = 0,79$). Для оценки деятельностных показателей — «Анкета самооценки готовности к педагогической деятельности» (24 утверждения по шкале Лайкерта, 4 субшкалы педагогической самоэффективности, $\alpha = 0,83$). Для оценки рефлексивных показателей — «Анкета

профессиональной рефлексии» (10 открытых вопросов и 5 шкальных оценок, обрабатываемых методом контент-анализа, коэффициент согласованности экспертов 0,83).

Формирующий этап продолжался две недели: участники самостоятельно проходили все четыре блока тренажёра (среднее суммарное время прохождения — 152 минуты). Статистическая обработка данных осуществлялась с применением критерия Вилкоксона для связанных выборок и коэффициента эффекта g .

Результаты эксперимента и их обсуждение

Результаты эксперимента по всем трём группам критериев представлены в таблице 1.

Таблица 1 — Сводные результаты педагогического эксперимента ($n = 35$)

Группа критериев	Пре-тест М	Пост-тест М	Прирост, %	r
Когнитивные (макс. 20 б.)	10,28	15,94	+55,1%	0,71
Деятельностные (макс. 120 б.)	64,25	92,20	+43,5%	0,68
Рефлексивные (макс. 20 б.)	11,99	16,80	+36,2%	0,59

Примечание: все различия статистически значимы при $p < 0,001$.

По когнитивным критериям средний балл теста нормативно-правовой базы вырос с 10,28 до 15,94 (прирост 55,1%). Наибольший прирост зафиксирован по субшкале «Экстренные ситуации» (+32,6%), что объясняется контекстуализированным характером усвоения нормативных знаний через сценарии: студенты встречались с правовыми нормами в конкретном профессиональном контексте, а не в абстрактном изложении учебника. Коэффициент эффекта $g = 0,71$ соответствует большому эффекту и превышает средний показатель метаанализа Черниковой ($g = 0,85$ при пересчёте в сопоставимые единицы).

По деятельностным критериям суммарный балл анкеты самооценки вырос с 64,25 до 92,20 (прирост 43,5%). Наиболее выраженный прирост наблюдается по субшкале правовой самооценки (+8,54 балла из 30), где исходный уровень был наименьшим. Данный результат согласуется с теорией самооценки Бандуры: студенты с исходно низкой самооценкой в конкретной области демонстрируют наибольший рост при успешном опыте. По деятельностным критериям $g = 0,68$.

По рефлексивным критериям зафиксированы значимые улучшения как по шкальным показателям, так и по качеству рефлексивных описаний. Тематический анализ открытых ответов выявил характерный переход: на пре-тесте 68% ответов не содержали анализа причин описанных затруднений, на пост-тесте данный показатель снизился до 29%. Участники стали значительно чаще рассматривать альтернативные стратегии действия и формулировать конкретные выводы о профессиональном развитии. $g = 0,59$.

Субъективная оценка тренажёра участниками подтвердила его высокую воспринимаемую ценность: средняя оценка реалистичности сценариев — 4,3/5, педагогической полезности — 4,5/5; 91% участников почувствовали большую уверенность перед предстоящей педагогической практикой; 94% отметили, что тренажёр помог им лучше понять реальные школьные ситуации.

Интерпретация результатов с опорой на теоретические основания позволяет выделить пять механизмов педагогического воздействия тренажёра: актуализация и систематизация знаний через практическое применение; расширение репертуара педагогических стратегий; формирование нормативно-правовой компетентности через контекстуализированное усвоение; снижение профессиональной тревожности через предварительный опыт; развитие профессиональной рефлексии через визуализацию последствий педагогических решений.

Ограничения исследования

К основным ограничениям исследования относятся: отсутствие контрольной группы (схема пре-тест/пост-тест без рандомизации); небольшой размер выборки ($n = 35$), ограничивающий субгрупповой анализ; локальность выборки (один университет, один регион); краткосрочность измерений без отсроченного пост-теста; самооценочный характер деятельностных критериев. Данные ограничения определяют направления последующих исследований: рандомизированный контролируемый эксперимент с контрольной группой на многовузовской выборке и лонгитюдные измерения устойчивости эффектов.

Заключение

Проведённое исследование позволяет сформулировать следующие выводы. Во-первых, разработанный интерактивный тренажёр является педагогически эффективным инструментом формирования профессиональной готовности будущих учителей математики: по всем трём группам критериев зафиксированы большие эффекты ($r = 0,59-0,71$), соответствующие уровню лучших мировых образцов симуляционного обучения. Во-вторых, тренажёр оказывает наиболее выраженное воздействие именно на те области профессиональной готовности, которые наименее охвачены традиционной подготовкой: правовую компетентность и самоэффективность в нестандартных ситуациях. В-третьих, нелинейная архитектура на основе графа состояний с динамическими метриками обеспечивает аутентичный опыт педагогических решений и эффективную обратную связь.

Разработанный тренажёр представляет собой готовый к применению образовательный инструмент, рекомендуемый к интеграции в учебный процесс педагогических специальностей казахстанских университетов в качестве подготовительного инструмента перед педагогической практикой.

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THE TRANSFORMATIVE ROLE OF ICT IN EDUCATION: NEW APPROACHES IN THE CONTEXT OF ARTIFICIAL INTELLIGENCE AND ADAPTIVE LEARNING

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Abstract: In modern education, the application of Information and Communication Technologies (ICT) has moved beyond a simple technical support role to become a transformative factor that fundamentally alters the content, methods, assessment mechanisms, and management models of teaching. The expansion of digital environments, the development of AI-based systems, learning analytics, and the proliferation of adaptive platforms have led education toward a more flexible, personalized, and data-driven decision-making structure.

This article examines the transformative role of ICT in the context of artificial intelligence (AI) and adaptive learning, systematizing the theoretical and practical foundations of new pedagogical approaches. AI technologies in education create value across several key areas: automated and objective assessment, intelligent tutoring systems that support individualized learning, predictive models based on learner behavior and performance indicators, and real-time content and task adaptation. These systems allow the identification of learners' strengths and weaknesses, enabling the construction of personalized learning trajectories.

Adaptive learning models, in turn, dynamically adjust instructional content through diagnostic assessments, continuous monitoring, and algorithmic decision-making, replacing the "one-size-fits-all" approach with personalized learning experiences. The analysis demonstrates that these technological approaches are associated with increased motivation, immediate feedback, cognitive load optimization, and improved learning outcomes.

Additionally, the teacher's role is transformed, shifting from a mere information provider to a learning designer and analytical decision-maker. The article highlights the hybrid teaching model – the collaboration of teachers and AI systems – as the most effective approach.

At the same time, the ethical and social risks of technology-driven transformation are evaluated: data privacy, algorithmic bias, digital inequality, and the potential negative impact of excessive automation on pedagogical quality are identified as key challenges.

The article concludes that, when applied within an appropriate methodological and ethical framework, ICT, AI, and adaptive learning systems have significant potential to enhance the quality, accessibility, and personalization of education, forming one of the central pillars of future educational models.

Keywords: ICT, artificial intelligence, adaptive learning, digital education, personalized instruction, learning analytics

TƏHSİLDƏ İKT-NİN TRANSFORMATOR ROLU: SÜNI İNTELLEKT VƏ ADAPTİV ÖYRƏNMƏ KONTEKSTİNDƏ YENİ YANAŞMALAR

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Giriş

XXI əsrdə təhsil sistemi sürətlə dəyişir və texnologiya bu dəyişikliklərin mərkəzində dayanır. Əvvəlcə informasiya-kommunikasiya texnologiyaları (İKT) yalnız tədrisə əlavə dəstək vasitəsi kimi qəbul olunurdusa, hazırda onlar tədris prosesinin bütün strukturunu və qiymətləndirmə mexanizmlərini transformasiya edən əsas faktorlara çevrilmişdir (Luckin, Holmes, Griffiths & Forcier, 2016; Holmes, Bialik & Fadel, 2019; UNESCO, 2021). Rəqəmsal platformalar, bulud texnologiyaları, böyük verilənlər və süni intellekt əsaslı alqoritmlər sayəsində öyrənmə prosesi ölçülə bilən, izləyə bilən və fərdiləşdirilə bilən bir sistemə çevrilmişdir. Bu dəyişiklik yalnız texnologiyanın tətbiqi deyil, həm də pedaqogik düşüncənin yenidən qurulması deməkdir.

Müasir təhsil siyasəti sənədlərində texnologiyanın transformativ təsiri xüsusi vurğulanır. UNESCO və OECD hesabatları rəqəmsal bacarıqlar və süni intellekt dəstəklə öyrənmə modellərinin gələcəyin əsas istiqamətləri olduğunu göstərir (UNESCO, 2021; Holmes et al., 2019). Təhsil sahəsində innovasiyaların qəbulunu sürətləndirən amillər arasında global rəqabət, iqtisadi inkişaf tələbləri və fərdiləşdirilmiş öyrənmə ehtiyacı da mühüm rol oynayır.

Bu məqalənin məqsədi İKT-nin transformator rolunu süni intellekt və adaptiv öyrənmə kontekstində sistemli şəkildə araşdırmaq, yeni pedaqoji yanaşmaları təqdim etmək və praktik tətbiq imkanlarını elmi əsaslarla izah etməkdir. Məqalədə həm nəzəri, həm də praktik aspektlərə toxunularaq təhsildə İKT-nin rolu bütün genişliyi ilə təqdim olunacaq.

İKT və təhsilin transformasiyası: konseptual çərçivə

İKT-nin təhsildə rolu inkişafın üç mərhələsində müşahidə olunur:

- Dəstək mərhələsi – Bu mərhələdə texnologiya əsasən vizual və multimediyə resursları kimi istifadə olunur. Məsələn, elektron kitablar, interaktiv qrafiklər və təqdimatlar müəllimlərin dərslərini dəstəkləyir. Bu mərhələdə texnologiya əlavə vasitə rolunu oynayır və müəllim hələ də öyrənmənin əsas yönləndiricisidir.

- İntegrasiya mərhələsi – LMS (Learning Management System) sistemləri, onlayn kurslar və hibrid təhsil modelləri tədris prosesini texnologiya ilə sıx integrasiya edir. Burada İKT yalnız vasitə deyil, həm də tədrisin koordinasiyası və qiymətləndirməsi üçün platforma rolunu oynayır. Misal üçün, onlayn imtahanlar, forumlar və elektron tapşırıq sistemləri müəllimlərə öyrənməni izləmək və effektiv idarə etmək imkanı verir.

- Transformasiya mərhələsi – Süni intellekt, adaptiv platformalar və öyrənmə analitikası vasitəsilə İKT tədrisin strukturunu dəyişdirir, pedaqoji qərarlarda aktiv rol oynayır və öyrənmə trayektoriyasını fərdiləşdirir. Sistem şagird davranışlarını analiz edir, proqnozlaşdırır və real vaxt rejimində tədrisi optimallaşdırır. Transformativ mərhələ konstruktivist və data-əsaslı pedaqogikanın kəşf etmə nöqtəsində formalaşır. Öyrənmə artıq statik proqram deyil, dinamik, fərdi və ölçülə bilən prosesə çevrilir (Luckin et al., 2016; Holmes et al., 2019).

Bu mərhələdə müəllim rolunu yalnız məlumat ötürücü kimi görmək artıq mümkün deyil; o, tədris dizayneri və fasilitator kimi çıxış edir. Texnologiya və pedaqogika birgə işləyərək öyrənmə nəticələrinin optimallaşdırılmasını təmin edir.

Süni intellektin təhsildə tətbiq modelləri

Süni intellekt təhsildə bir neçə əsas istiqamətdə tətbiq olunur:

- Avtomatlaşdırılmış qiymətləndirmə – AI testləri, yazı işləri və açıq cavabları avtomatik qiymətləndirir, müəllimlərin iş yükünü azaldır və qiymətləndirmədə standartlaşmanı təmin edir.

- Ağıllı repetitor sistemləri – Şagirdin səhv və uğurlu davranış modellərini tanıyır, ona uyğun fərdi izah strategiyası seçir. Bu sistemlər müəllimlərin fərdi yanaşmasına yaxınlaşır və şagirdin zəif mövzularını effektiv üzə çıxarır.

- Öyrənmə analitikası – Şagird davranış məlumatları əsasında risk qrupları və zəif mövzular müəyyən edilir. Erkən müdaxilə imkanı yaranır və tədris planı fərdiləşdirilir.

- Məzmunun dinamik uyğunlaşdırılması – AI şagirdin səviyyəsinə görə tapşırıq çətinliyini və təqdimat formasını dəyişir, idrak yükünü optimallaşdırır.

Tədqiqatlar göstərir ki, AI dəstəklə fərdiləşdirmə modelləri öyrənmə nəticələrini statistik olaraq əhəmiyyətli dərəcədə yaxşılaşdırır (Luckin et al., 2016; Woolf, 2010). Məsələn, riyaziyyat dərslərində adaptiv platformalar şagirdlərin hər səhvindən dərhal öyrənməyə imkan verir və müəllimlər üçün konkret tövsiyələr təqdim edir. Dil öyrənmədə isə səviyyə əsaslı dinamik məşqlər şagirdin danışıq və yazı bacarıqlarını fərdiləşdirilmiş şəkildə inkişaf etdirir.

Adaptiv öyrənmə: nəzəri əsas və texnoloji mexanizm

Adaptiv öyrənmə sistemi öyrənənin performansına əsasən real vaxt rejimində tədris məzmununu dəyişən modeldir. Onun əsas komponentləri: diaqnostik qiymətləndirmə, davamlı monitorinq, alqoritmik qərar mexanizmi və fərdi məzmun xəritəsidir. Sistem hər cavabdan sonra ehtimal modelini yeniləyir və növbəti addımı seçir, beləliklə, “bir proqram hamı üçün” modeli yerinə “fərdi öyrənmə trayektoriyası” modeli tətbiq olunur (Holmes et al., 2019; UNESCO, 2021).

Bu model şagirdin öyrənmə tempini, diqqət sahələrini və öyrənmə davranışlarını analiz edir. Adaptiv sistemlər həmçinin qrup dinamikasını izləyərək, sınıfdə fərqli səviyyəli şagirdlərin həm fərdi, həm də kollektiv öyrənmə trayektoriyalarını optimallaşdırır.

Didaktik üstünlüklər və pedaqoji təsir

- Adaptiv və AI əsaslı İKT modelləri aşağıdakı üstünlüklərə malikdir:
- Fərdiləşdirmə – hər şagird öz sürətində və çətinlik səviyyəsində irəliləyir.
- Motivasiya artımı – uyğun çətinlik səviyyəsi “uğur ehtimalını” artırır və motivasiyanı qoruyur.

- Geri bildirim operativliyi – dərhal rəy öyrənməni möhkəmləndirir.

- Metakognitiv dəstək – şagird öz inkişafını izləyə bilir, zəif sahələri görür və özünü tənzimləyir.

Araşdırmalar göstərir ki, fərdiləşdirilmiş adaptiv mühitlərdə davamlılıq və tapşırıq tamamlama faizi ənənəvi modellərlə müqayisədə daha yüksək olur (Luckin et al., 2016). Bu da öyrənmənin səmərəliliyini artırır və müəllimlər üçün həm strateji, həm də əməliyyat planlamasında əhəmiyyətli məlumatlar təmin edir.

Müəllim rolunun transformasiyası

Texnologiyanın güclənməsi müəllimi əvəz etmir, onun rolunu dəyişir:

- Məlumat ötürücüdən → öyrənmə dizaynerinə

- Qiymətləndiricidən → analitik qərarverənə

- Nəzarətçidən → fasilitatora

Müəllim AI sistemlərinin təqdim etdiyi analitik məlumatları şərh edir və pedaqoji qərara çevirir. Bu model “insan + maşın” əməkdaşlığına əsaslanır (Holmes et al., 2019). Müəllim şagirdlərin fərdi ehtiyaclarını nəzərə alaraq dərslər planlarını və tapşırıqları tənzimləyir, AI tərəfindən verilən tövsiyələrdən istifadə edir, lakin pedaqoji qərarlar hələ də insana aiddir.

Risqlər və etik məsələlər

AI tətbiqlərində diqqət yetirilməsi vacib olan risklər:

- Məlumat təhlükəsizliyi – şagird məlumatlarının toplanması və emalı etik çərçivədə aparılmalıdır.

- Alqoritmik qəraz – təlim verilənləri qərazlıdırsa, nəticələr də qərazlı ola bilər.
- Rəqəmsal bərabərsizlik – texnologiyaya çıxış fərqləri nəticə bərabərsizliyi yarada bilər.
- Pedaqoji sadələşmə riski – həddindən artıq avtomatlaşdırma dərslər prosesində dərinliyi azalda bilər (UNESCO, 2021).

Yeni metodoloji yanaşmalar və praktik tətbiq ssenariləri

Hibrid adaptiv model – AI + müəllim qərarı birlikdə işləyir.

Mikro-adaptiv məzmun – tapşırıq daxilində çətinlik dinamik dəyişir.

Analitika əsaslı kurikulum dizaynı – məlumatlar proqram yenilənməsinə yön verir.

Süni intellekt dəstəklili formativ qiymətləndirmə – qiymətləndirmə tədrisin ayrılmaz hissəsinə çevrilir.

Praktik tətbiq nümunələri: riyaziyyat və proqramlaşdırmada adaptiv tapşırıq bankları, dil öyrənmədə səviyyə əsaslı dinamik məşqlər, STEM sahəsində simulyasiya əsaslı AI dəstəyi və erkən xəbərdarlıq sistemi ilə riskli şagirdlərin aşkarlanması (Luckin et al., 2016; Holmes et al., 2019).

Nəticə

İKT artıq təhsildə köməkçi vasitə deyil, transformator gücə malik sistem komponentidir. Süni intellekt və adaptiv öyrənmə modelləri tədrisi fərdiləşdirir, ölçülə bilən edir və daha səmərəli qurmağa imkan verir. Bununla yanaşı, etik, metodoloji və sosial risklər nəzərə alınmalı, müəllim faktoru mərkəzdə saxlanmalıdır. Gələcəyin effektiv təhsil modeli texnologiya və pedaqogikanın balanslı inteqrasiyasına əsaslanacaqdır (Holmes et al., 2019; UNESCO, 2021; Luckin et al., 2016).

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Philological Sciences

The Nature of Language Change

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Abstract. The presented study discusses the nature of language change caused by its internal and external elements. It reviews changes brought about by internal and external factors. Internal factors relate to the inherent laws of language development and include changes in spelling, pronunciation, grammar, and vocabulary. External factors, on the other hand, are connected with political, social, cultural, and educational conditions outside the language itself, such as migration, military conquests, language contact, bilingualism, industrialization, social and economic fluctuations, educational policy, and so on.

We discuss the existence of many different ways in which language changes occur, such as language change during the learning process, linguistic change through social differentiation, and linguistic change through natural processes arising from language use.

It is noted that in modern linguistics there is an increasingly widespread recognition of the approach that language change should be considered as the result of the interaction between internal and external factors. For example, structural possibilities (internal motivation) are sometimes realized only when there is social pressure or a favorable context for the spread of innovation. Consequently, a comprehensive analysis of language change requires consideration not only of the logic of the linguistic system, but also of the social experience and behavioral patterns of language users.

Keywords: language change, the nature of language change, internal and external elements.

Internal and External Elements of Language Change

The essential nature of language change can be expressed through four concepts: inevitability, continuity, systematicity, and regularity.

Language change can generally be divided into two types: change caused by the structural aspects of language itself — internally motivated change — and change conditioned by externally motivated factors.

Internal factors relate to the inherent laws of language development and include changes in spelling, pronunciation, grammar, and vocabulary. External factors, first and foremost, are connected with the symbolic role of language in society. They are associated with political, social, cultural, and educational conditions outside the language itself, such as migration, military conquests, language contact, bilingualism, industrialization, social and economic fluctuations, educational policy, and so on.

Internally motivated change usually leads to balance within the system, the elimination of marked elements, the analogical spread of regular forms, or similar processes. Since languages consist of different levels, a change at one level may cause imbalance at another. For example, a change in pronunciation may affect the morphology of a language.

Another example of internal change is what is known as “analogy.” This term has several meanings; however, its definition may be paraphrased as “the regularization of an irregular set of forms (paradigms)” (Hickey, 2010: 3.1.1).

Thus, internal language change is connected to the grammatical system. External language change and development, on the other hand, are studied by sociolinguistics through the examination of socio-cultural factors occurring within society that influence language.

The extent to which speakers are aware of language change depends on the level of impact. A change involving a closed class of segments is not as noticeable to speakers as a change occurring within an open class. An example of the latter type is lexical change, which is the easiest for speakers to perceive.

Since ancient times, speakers have regarded language change as linguistic deterioration. There are two main reasons for this. One is the general tendency toward stability and resistance to change; the other is the association of language change with a particular social group.

A speaker may eventually adapt to a change, no matter how unpleasant it initially appears. Language change is not the goal of speakers. It is what is called an “epiphenomenon” — something that happens, but not intentionally from a linguistic point of view. Epiphenomenon means that change occurs due to internal or external causes — or a combination of both — but the change itself is not deliberate. It is impossible to predict either internal or external language change (Hickey, 2010: 3.1.3).

When members of a small group migrate to another region, they often shift to the language of the host society. It is also possible that, as a result of large-scale migration, the local population may shift to the migrants’ language. This is especially common in situations where the local population is militarily defeated by the migrating group (Matiki, 1997: 4). Speakers of languages with lower social status become bilingual as a result of language contact in order to participate in the social, economic, and political life of the country. If government policy also supports education only in the dominant nation’s language, the preservation of minority languages becomes even more difficult, which directly affects the functioning of the language and leads to changes within it.

Changes caused by language contact may contribute to the creation of new languages. Linguistic systems that develop in the absence of a shared linguistic background among people who need to communicate for trade, political, or other purposes are known as pidgins. Pidgins are characterized by limited morphology, a stronger reliance on word order, and a relatively small vocabulary. Some lexical items may be macaronic, meaning that they consist of elements from two or more different languages, although this is not always the case (Grant, 2020).

There are many different ways in which language change can occur. One of them is language change through the process of transmission and learning: language is transformed as it is passed from one generation to another. Each individual must reconstruct grammar and vocabulary on the basis of the linguistic input received from other members of the speech community.

Language change may also occur through social differentiation. The desire for distinction and social advancement has been considered one of the driving factors of linguistic change. Social groups adopt specific styles of dress, ornamentation, gestures, behavioral norms, and other distinguishing features, and language forms part of this process. Linguistic distinctiveness may be achieved through vocabulary choices (such as slang or jargon), pronunciation, morphological processes, syntactic constructions, and other linguistic features.

Sociolinguistic studies demonstrate that group identity is an especially important factor in the context of language change. According to a widely held view, members of lower social classes intentionally modified their speech in imitation of the social elite in order to improve their social standing. At the same time, elite groups also altered their language in order to maintain distance from the masses (Labov, 1994).

William Labov, in his article *The Social Motivation of a Sound Change*, emphasizes the social motivation behind linguistic change and demonstrates how sound change may function as a means of expressing group identity (Labov, 1963).

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Poetic Translation as Cross-Linguistic Mediation in Foreign Language Teaching: A Conceptual Pedagogical Model

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Abstract

This article addresses a conceptual gap at the intersection of pedagogical translation, literature-based foreign language teaching, cross-linguistic mediation, and reflective writing. Although translation has been reconsidered as a useful resource in language teaching, poetic translation remains insufficiently modelled as a distinct classroom practice that links interpretation, mediation, and learner reflection. Similarly, poetry is often valued for cultural and literary engagement, while reflective writing is associated with metacognitive awareness; however, these areas are rarely integrated into a single pedagogical framework. Using an integrative conceptual review based on theory synthesis and model construction, this article proposes the Poetic Translation Mediation Cycle. The model consists of seven stages: contextual orientation, interpretive reading, lexical-semantic mapping, draft translation, mediation decision-making, reflective translation commentary, and revision through discussion. The article does not claim empirical effectiveness. Instead, it offers a theoretically grounded and classroom-oriented framework for future application and research in foreign language teaching.

Keywords: poetic translation; foreign language teaching; pedagogical translation; cross-linguistic mediation; reflective writing; literature-based language teaching

1. Introduction

Translation has long occupied a debated position in foreign language teaching. Because of its historical association with the grammar-translation method, it has often been regarded as a traditional practice that may encourage dependence on the first language, privilege written accuracy, and reduce communicative use. However, recent scholarship has challenged this narrow view. Translation is increasingly reconsidered not as a mechanical transfer of words, but as a pedagogical resource that can support language awareness, intercultural understanding, multilingual comparison, and learner reflection (Cook, 2010; Laviosa, 2014; Pintado Gutiérrez, 2021).

This reconsideration is particularly relevant in foreign language classrooms where learners naturally compare linguistic systems and use their existing linguistic repertoires to understand new texts. The CEFR Companion Volume strengthens this perspective by placing mediation alongside reception, production, and interaction as a central mode of communication

(Council of Europe, 2020). In this view, language users are not merely receivers or producers of linguistic forms; they are social agents who make meaning accessible across linguistic, cultural, textual, and communicative boundaries. Translation can therefore be understood as one possible form of mediation.

Yet not all translation tasks are pedagogically equivalent. Translating isolated sentences, informational texts, pragmatic messages, and poems involve different forms of linguistic and interpretive work. Poetic translation is particularly complex because poetry condenses language. It foregrounds metaphor, ambiguity, rhythm, sound, image, tone, cultural memory, and aesthetic effect. A learner translating a poem cannot rely only on lexical equivalence or grammatical accuracy. The learner must first interpret how meaning is produced in the poem and then decide how that meaning can be reconstructed in another language.

For this reason, poetic translation deserves a more specific pedagogical model than general arguments in favor of classroom translation can provide. The literature on pedagogical translation has helped rehabilitate translation as a language-learning tool, but it often discusses translation broadly. The literature on poetry and literature in foreign language teaching has shown that literary texts can support close reading, cultural awareness, critical thinking, and aesthetic engagement (McKay, 1982; Paesani, 2011). However, it does not always explain how translation can structure these processes. Similarly, reflective writing has been widely discussed as a tool for metacognitive awareness, yet its specific role in making poetic translation decisions visible remains underdeveloped (Knospe, 2018; Wärnsby, Kauppinen, & Finnegan, 2021).

The central gap addressed in this article is therefore not the absence of studies on translation, poetry, mediation, or reflection separately. Rather, the gap lies in the insufficient integration of these areas into a single pedagogical model. Existing literature has not adequately systematized poetic translation as a mediation-based classroom cycle that connects interpretive reading, translation decision-making, reflective commentary, and revision.

This article responds to that gap through an integrative conceptual review. It brings together four bodies of literature: pedagogical translation, CEFR-based mediation, poetry and literature in foreign language teaching, and reflective writing/metacognition. The purpose is not to measure the effectiveness of poetic translation in a particular classroom or to present empirical findings about learner development. Instead, the article uses theory synthesis and model construction to develop a conceptual framework for organizing poetic translation as cross-linguistic mediation in foreign language teaching.

The article is guided by the following question: How can poetic translation be theoretically modelled as a cross-linguistic mediation practice that integrates interpretive reading, translation decision-making, reflective writing, and revision in foreign language teaching?

The main result of the article is the Poetic Translation Mediation Cycle, a seven-stage pedagogical model consisting of contextual orientation, interpretive reading, lexical-semantic mapping, draft translation, mediation decision-making, reflective translation commentary, and revision through discussion. The contribution of the article is conceptual and pedagogical. Conceptually, it reframes poetic translation as a form of cross-linguistic mediation. Pedagogically, it proposes a structured model that teachers and researchers can adapt for classroom design, reflective translation tasks, and future empirical studies.

2. Literature Background and Research Gap

The article is located at the intersection of four areas: pedagogical translation, CEFR-based mediation, poetry/literature in foreign language teaching, and reflective writing. Each area contributes important insights to language pedagogy. However, they have not been sufficiently integrated into a model that explains how poetic translation may function as cross-linguistic mediation linking interpretation, translation decision-making, reflection, and revision.

2.1. Pedagogical Translation and Language Teaching

Translation has often been treated with caution in modern language pedagogy because of its association with the grammar-translation method. Nevertheless, recent work has questioned the exclusion of translation from foreign language teaching. Cook (2010) argues that translation deserves reassessment because learners naturally compare languages and because translation can relate the target language to learners' existing linguistic resources. Laviosa (2014) similarly proposes a translation-based pedagogy that connects language learning, culture, and translation within the same educational environment.

This renewed interest has helped move translation beyond its older association with mechanical sentence conversion. Translation can now be viewed as a pedagogical tool for language awareness, intercultural comparison, textual analysis, and multilingual learning. Pintado Gutiérrez (2021) further shows that translation in language teaching, pedagogical translation, and code-switching require careful conceptual boundary-setting in classroom contexts.

However, this literature often discusses translation in broad terms. Translating isolated sentences, cultural references, pragmatic messages, and poems are not the same type of task. Poetry translation requires particular attention because it involves not only linguistic transfer but also interpretive, aesthetic, and cultural decision-making. This creates the first gap addressed in the article: poetic translation remains insufficiently systematized as a distinct form of pedagogical mediation.

2.2. Mediation and Cross-Linguistic Meaning-Making

The CEFR Companion Volume offers an important framework for reconsidering translation in contemporary language teaching. Mediation is presented as one of the major modes of communication, alongside reception, production, and interaction (Council of Europe, 2020). In mediation, learners do not only receive or produce language; they help make meaning accessible across linguistic, cultural, semantic, or communicative barriers.

This concept is especially relevant to poetic translation. A learner translating a poem does not simply transfer a text from one language to another. The learner interprets the poem, identifies significant meanings and effects, decides which elements can be preserved or transformed, and reformulates them for a new linguistic and cultural audience. In this sense, poetic translation can be understood as cross-linguistic mediation.

Žindžiuvienė (2023) emphasizes that mediation is increasingly relevant in foreign language classes because it involves explaining, reformulating, and facilitating meaning. This supports the argument that poetic translation should be framed not as a narrow linguistic exercise but as a form of mediated meaning-making. However, mediation theory does not by itself provide a classroom sequence for poetry translation. This creates the second gap: a specific mediation-based cycle for poetic translation in foreign language teaching remains underdeveloped.

2.3. Poetry, Literature, and Interpretive Reading

The literature on literature in foreign language teaching has shown that literary texts can support cultural awareness, close reading, discussion, aesthetic response, and critical thinking. McKay (1982) argues that literature can have a meaningful place in ESL classrooms if texts are carefully selected and pedagogically mediated. Paesani (2011) also calls for more integrated language-literature instruction, suggesting that literary texts can bridge linguistic development and interpretive engagement.

Poetry is especially valuable because it condenses language and foregrounds metaphor, sound, ambiguity, rhythm, symbolic meaning, and emotional intensity. These features make poetry difficult for learners, but they also make it pedagogically rich. Poetry encourages learners to slow down and attend to how language produces meaning. Maley and Duff (1989) show that poetry can be used in the language classroom not only for literary appreciation but also for language awareness, discussion, and creative engagement.

Recent work on poetry translation in educational contexts provides an even closer basis for the argument of this article. Beauvais (2019) examines children's poetry translation in the literature classroom and shows how translation can produce an emergent literary awareness. Brookman and Robinson (2016) connect translation, creativity, and the teaching of poetry, demonstrating that translation can become a productive pedagogical activity rather than a secondary linguistic exercise.

Nevertheless, poetry pedagogy often focuses on reading, discussion, appreciation, or creative response. It does not always explain how translation can intensify interpretive reading. When learners translate a poem, they must decide how an image works, whether a metaphor should be preserved or adapted, whether ambiguity should remain open, and how culturally marked expressions can be reconstructed in the target language. Translation therefore turns interpretation into an active and consequential process. This creates the third gap: the specific role of poetic translation in deepening interpretive reading has not been sufficiently modelled.

2.4. Reflective Writing and Translation Commentary

Reflective writing has been widely discussed as a means of developing metacognitive awareness. In foreign language teaching, reflection can help learners become aware of their learning strategies, difficulties, progress, and decision-making processes. Knospe (2018) emphasizes the importance of metacognitive knowledge in foreign language writing, while Wårnsby et al. (2021) show how reflective writing in ESL contexts can provide access to metacognition and inform curriculum design and assessment.

This is directly relevant to poetic translation. A translation product alone does not fully reveal the learner's thinking. A student may produce a target-language version of a poem, but the teacher may not know why a metaphor was changed, why rhythm was abandoned, why a cultural image was simplified, or why a literal expression was preserved. Without reflection, poetic translation remains primarily a product. With reflection, it becomes evidence of interpretive and strategic reasoning.

Translation studies has also developed work on translation commentary, guided commentary, and self-reflection. Shei (2005) presents translation commentary as a bridge between translation curriculum and English for Academic Purposes. Shih (2018) re-examines translation commentary from the perspective of translator educators and highlights its pedagogical and assessment value. Norberg (2014) emphasizes the value of guided commentaries in fostering self-reflection among translation students, while Pietrzak (2019) argues for scaffolding student self-reflection in translator training.

However, reflective writing has not been sufficiently conceptualized as a tool for making poetic translation decisions visible, discussable, and assessable in foreign language teaching. This article responds to that gap by proposing Reflective Translation Commentary as a component of the Poetic Translation Mediation Cycle.

2.5. The Combined Gap

Taken separately, the four literatures discussed above provide important insights. Pedagogical translation rehabilitates translation as a language-learning resource. CEFR-based mediation offers a theoretical language for cross-linguistic meaning-making. Poetry pedagogy highlights the interpretive and aesthetic value of literary texts. Reflective writing explains how learners can become aware of their own thinking.

Yet their intersection remains insufficiently systematized. Existing literature does not adequately explain how poetic translation can be organized as a mediation-based classroom cycle that moves from contextual orientation and interpretive reading to translation decision-making, reflective commentary, and revision through discussion. In response, the article proposes the Poetic Translation Mediation Cycle as a theory-informed pedagogical framework for foreign language teaching.

3. Methodological Approach: Integrative Conceptual Review

This article adopts an integrative conceptual review as its methodological approach. Since the purpose is not to measure the effectiveness of poetic translation in a specific classroom setting, it does not employ experimental, survey-based, ethnographic, or statistical methods. No learner translations, classroom observations, interviews, or assessment scores are analyzed. Instead, the article develops a theoretically grounded pedagogical model by synthesizing related bodies of literature.

The choice of an integrative conceptual review is appropriate for two reasons. First, the central problem is distributed across different research areas rather than located within one field. Pedagogical translation, mediation, poetry/literature pedagogy, and reflective writing each explain part of the problem, but none of them alone provides a complete model for poetic translation as a mediation-based classroom practice. Second, the article aims not simply to summarize existing literature, but to reorganize it conceptually in order to propose a pedagogical framework.

This methodological orientation is consistent with the view that literature reviews can function as research methodologies when conducted with explicit purpose, structure, and analytical logic (Snyder, 2019). It also corresponds to Jaakkola's (2020) account of conceptual articles, particularly the use of theory synthesis and model construction as legitimate forms of conceptual contribution.

The review followed four analytical stages. First, the relevant conceptual domains were selected: pedagogical translation, CEFR-based mediation, poetry/literature in foreign language teaching, and reflective writing/metacognition. Second, the main contribution and limitation of each domain were mapped. Third, these domains were synthesized through a cross-domain logic: poetry requires interpretive reading; translation requires reformulation; poetic translation requires mediation decisions; mediation decisions become pedagogically visible through reflective writing; and reflection and discussion allow revision. Fourth, this synthesis was used to construct the Poetic Translation Mediation Cycle.

The methodological scope of the article is conceptual rather than empirical. Therefore, the article does not claim that the proposed model improves learners' interpretive reading, writing ability, translation competence, or metacognitive awareness. Such claims would require classroom-based empirical studies. The value of the method lies instead in conceptual clarification and pedagogical model-building.

4. The Poetic Translation Mediation Cycle

The main conceptual result of this article is the Poetic Translation Mediation Cycle. The model organizes poetic translation as a structured form of cross-linguistic mediation in foreign language teaching. It does not present poetic translation as a mechanical transfer from a source text into a target text. Rather, it frames poetic translation as a process in which learners interpret a poem, identify linguistic and aesthetic difficulties, make mediation decisions, explain those decisions through reflective commentary, and revise their translations through discussion.

The model should be understood as a flexible pedagogical framework rather than a rigid instructional sequence. Teachers may adapt its stages according to learner proficiency, language pair, poetic tradition, classroom time, and curricular aims. However, the order of the stages reflects an important principle: learners should not be asked to translate poetry before they have been guided to interpret it. In this model, translation comes after contextual and interpretive preparation, and reflection comes after translation.

4.1. Stage Overview

Stage	Learner task	Pedagogical function
1. Contextual orientation	Understand the poem's basic literary, cultural, and thematic context	Prepares learners for meaningful interpretation
2. Interpretive reading	Analyze imagery, tone, metaphor, ambiguity, and structure	Develops close and interpretive reading
3. Lexical-semantic mapping	Identify difficult words, images, cultural references, and semantic layers	Builds linguistic and semantic awareness
4. Draft translation	Produce an initial target-language version	Transforms interpretation into cross-linguistic production
5. Mediation decision-making	Examine what is preserved, adapted, transformed, omitted, or compensated	Makes translation a conscious mediation process
6. Reflective translation commentary	Explain major translation decisions in writing	Develops metacognitive and reflective awareness
7. Revision through discussion	Compare versions, discuss alternatives, and revise	Turns translation into dialogic and process-based learning

4.2. Contextual Orientation and Interpretive Reading

The first stage is contextual orientation. Before translating a poem, learners need sufficient contextual preparation to approach it as a meaningful literary and cultural text. This preparation may include brief information about the poet, historical background, genre, central theme, cultural references, and key symbolic elements. The aim is not to provide an exhaustive literary lecture, but to create the minimum conditions required for interpretation.

This stage is especially important because poetic meaning often depends on cultural memory, intertextual references, religious or philosophical vocabulary, and historically specific images. Without contextual support, learners may reduce the poem to isolated words or dictionary meanings. With excessive explanation, however, learners may become passive receivers of the teacher's interpretation. Therefore, contextual orientation should be selective, functional, and open-ended (McKay, 1982; Paesani, 2011).

The second stage is interpretive reading. Learners read the poem not only for literal comprehension but also for meaning-making. They examine how the poem produces its effects through imagery, metaphor, tone, repetition, rhythm, contrast, ambiguity, and silence. The guiding question is not simply "What does the poem say?" but "How does the poem create meaning?" Work on language-literature instruction and poetry translation similarly emphasizes the need to connect literary reading with active meaning-making (Paesani, 2011; Beauvais, 2019).

4.3. Lexical-Semantic Mapping and Draft Translation

The third stage is lexical-semantic mapping. After interpretive reading, learners identify words, phrases, images, and expressions that may create translation difficulties. These may include metaphors, idioms, archaic terms, culturally marked expressions, sound patterns, symbolic images, or emotionally charged vocabulary. The purpose of this stage is to prevent students from

moving too quickly from source word to target equivalent. In poetry, a word may carry literal meaning, metaphorical meaning, cultural association, emotional tone, and sound value at the same time.

The fourth stage is draft translation. Learners produce an initial target-language version of the poem or selected lines. This draft should be understood as provisional. Its purpose is not to produce a perfect literary translation, but to transform interpretation into cross-linguistic production.

Draft translation is pedagogically important because it exposes the gap between understanding and expression. Learners may feel that they understand the poem during discussion, but translation requires them to reconstruct that understanding in another linguistic system. A metaphor may resist direct transfer; rhythm may disappear; a cultural expression may sound strange; an emotionally subtle line may become too explicit or too weak. This productive difficulty is one of the main values of poetic translation. It forces learners to recognize that meaning is produced through the relation between words, images, cultural expectations, sound, form, and reader response (Laviosa, 2014; Beauvais, 2019).

4.4. Mediation Decision-Making

The fifth stage is mediation decision-making. This is the conceptual center of the model. At this stage, learners examine the decisions behind their draft translations. They ask not only whether their translation is correct, but what kind of mediation it performs.

A poetic translation decision may involve preserving an image, adapting an image, explaining a cultural reference, maintaining ambiguity, prioritizing semantic meaning over rhythm, prioritizing poetic effect over literal accuracy, compensating for a lost sound or image, or leaving a foreign element visible in order to preserve cultural distance.

This stage reframes translation as conscious mediation. The learner becomes aware that translation involves choices between competing values: accuracy, readability, aesthetic effect, cultural resonance, ambiguity, rhythm, and emotional tone. This corresponds to the CEFR-based understanding of mediation as meaning-making across linguistic and cultural boundaries (Council of Europe, 2020). It also resonates with translation competence research, where strategic decision-making and task awareness are central to translation development (Hurtado Albir, 2015).

4.5. Reflective Translation Commentary

The sixth stage is reflective translation commentary. This component makes the learner's reasoning visible. A translation product alone does not show why a student made certain choices. The commentary allows learners to explain their interpretive and translational decisions in writing.

Reflective translation commentary should be short, focused, and guided. It should not become a general emotional response to the poem. Instead, it should ask learners to identify and justify specific decisions. Useful prompts include: What was the most difficult element of the poem to translate? Which word, image, or line required the most important decision? What did you try to preserve from the original? What did you change, adapt, or omit? Was anything lost in translation? Did you try to compensate for that loss? What effect did you want to create for the target-language reader? If you revised the translation, what did you change and why?

This stage connects poetic translation with metacognitive awareness. Learners begin to think about their own thinking. They become aware of strategies, uncertainties, compromises, and interpretive assumptions. Translation commentary has already been discussed as a valuable bridge between translation curriculum, academic writing, assessment, and learner reflection (Shei, 2005; Shih, 2018). Guided commentary and scaffolded self-reflection have also been shown to support reflective development in translator training contexts (Norberg, 2014; Pietrzak, 2019). This article adapts those insights to poetic translation in foreign language teaching.

4.6. Revision Through Discussion

The final stage is revision through discussion. Learners compare different translations, discuss alternatives, and revise their own versions. This stage emphasizes that translation, like writing, is a process. A first draft is not the end of learning; it is the basis for reflection, dialogue, and improvement.

Discussion should not be organized around finding one correct translation too quickly. Instead, the teacher can guide students to compare versions according to specific criteria: Which version preserves the central image more effectively? Which version communicates the emotional tone better? Which version keeps the ambiguity of the original? Which version sacrifices poetic effect for literal accuracy? Which choices are best justified in the reflective commentary?

Through comparison, learners see that translation is not only a linguistic operation but also a dialogic act of interpretation. Different translations reveal different readings of the same poem. Revision through discussion therefore develops linguistic sensitivity, interpretive tolerance, and reflective awareness.

4.7. The Logic of the Cycle

The seven stages of the Poetic Translation Mediation Cycle are connected by a clear pedagogical logic. Contextual orientation prepares learners for interpretation. Interpretive reading helps them identify what matters in the poem. Lexical-semantic mapping turns interpretation into linguistic awareness. Draft translation transforms reading into cross-linguistic production. Mediation decision-making makes translation choices conscious. Reflective translation commentary makes those choices visible and assessable. Revision through discussion turns the process into collaborative learning.

The model integrates four dimensions of foreign language teaching: an interpretive dimension, in which learners analyze poetic meaning; a linguistic dimension, in which they compare meanings and forms across languages; a mediational dimension, in which they reconstruct meaning for another linguistic and cultural audience; and a reflective dimension, in which they explain and revise their decisions.

The originality of the model does not lie in inventing each stage separately. Contextual preparation, close reading, drafting, reflection, and revision are already familiar educational practices. The originality lies in integrating them into a mediation-based cycle specifically designed for poetic translation in foreign language teaching.

5. Pedagogical Implications for Foreign Language Teaching

The Poetic Translation Mediation Cycle has several implications for foreign language teaching. Since the model is conceptual rather than empirically validated, these implications should not be read as proven classroom effects. Rather, they indicate how poetic translation may be organized pedagogically if teachers wish to use it as a structured mediation-based activity.

5.1. Text Selection and Scaffolding

Not every poem is suitable for foreign language learners, and not every poem is suitable for translation-based classroom work. Teachers should select texts according to linguistic level, cultural accessibility, poetic density, length, and pedagogical purpose. A poem that is too linguistically complex may create frustration rather than interpretation. A poem that is too culturally distant may require so much explanation that learners become passive. Conversely, a poem that is too simple may not generate meaningful translation decisions.

For lower and intermediate levels, short poems, selected stanzas, couplets, or image-based texts may be more appropriate than long and formally complex poems. At advanced levels, more demanding poetic texts can be introduced, especially when learners have enough linguistic and cultural knowledge to discuss metaphor, ambiguity, intertextuality, and tone. This implication is consistent with literature-based language pedagogy, which emphasizes text selection, learner

readiness, and meaningful engagement with literary language (McKay, 1982; Maley & Duff, 1989; Paesani, 2011).

Scaffolding is equally important. Translation should not be the first classroom task. If learners are asked to translate a poem immediately, they may rely on dictionaries, literal substitution, or surface-level equivalence. Contextual orientation, interpretive reading, and lexical-semantic mapping should therefore precede draft translation.

5.2. Translation as Decision-Making

The model changes how translation is explained to learners. In many classroom contexts, students assume that translation means finding the correct equivalent. This assumption is especially problematic in poetry, where a word, image, or line may carry several meanings at once. Teachers should therefore present poetic translation as decision-making rather than equivalence-seeking.

This does not mean that accuracy becomes irrelevant. Learners still need to understand the source text and produce a coherent target-language version. However, accuracy must be balanced with other values: imagery, tone, rhythm, ambiguity, cultural resonance, emotional effect, and readability. Students should learn that translation often involves choosing between competing priorities. This process-oriented view is consistent with translation-based pedagogy and translation competence research, both of which emphasize strategic awareness and task-based decision-making (Laviosa, 2014; Hurtado Albir, 2015).

A useful classroom question is not simply "Is this translation correct?" but "What does this translation preserve, and what does it lose?" This question helps learners think like mediators. A literal translation may preserve source structure but weaken poetic effect. A freer translation may sound natural but lose cultural specificity. An explanatory translation may clarify meaning but reduce ambiguity.

5.3. Reflective Translation Commentary

One of the strongest pedagogical implications of the model is the use of Reflective Translation Commentary. After producing a draft translation, learners should write a short commentary explaining their main choices. This commentary may consist of one paragraph or a set of guided responses. What matters is that learners articulate the reasoning behind their decisions.

This practice has several benefits. First, it makes the learner's thinking visible. Second, it helps students become aware of translation as a process. Third, it gives teachers a richer basis for assessment. Fourth, it connects translation with academic writing because students must justify their choices using textual reasoning. These functions are supported by translation commentary and guided self-reflection research, which has shown that commentary can help learners articulate and evaluate translation decisions (Shei, 2005; Shih, 2018; Norberg, 2014; Pietrzak, 2019).

Reflective commentary is especially useful in poetry translation because the final product alone may be misleading. A student's translation may appear unusual, but the commentary may reveal a thoughtful interpretive decision. Another translation may be fluent, but the commentary may show that the learner ignored key imagery or cultural meaning. Assessment should therefore include both the translation and the commentary.

5.4. Assessment and Classroom Discussion

The model requires a broader approach to assessment. If poetic translation is assessed only according to lexical accuracy or grammatical correctness, its interpretive and mediational dimensions are lost. Teachers should develop rubrics that include several dimensions: source-text understanding, interpretive awareness, cross-linguistic reformulation, mediation decision-making, reflective commentary, target-language expression, and revision. Translation competence and reflective writing research both support the need for assessment approaches that consider

process, decision-making, and learner awareness rather than product accuracy alone (Hurtado Albir, 2015; Wårnsby et al., 2021).

Classroom discussion should also value multiple translations. Poetry translation should not be organized around the immediate discovery of one correct answer. Different students may produce different versions, and these differences can become valuable material for discussion. Teachers may ask which version preserves the central image more successfully, which version sounds more natural in the target language, which version keeps ambiguity, and which decisions are best justified in the reflective commentary.

Such discussion helps learners understand translation as a dialogic process. It also teaches them to evaluate language choices critically. Instead of seeing difference only as error, students learn to see difference as an opportunity for interpretation.

5.5. Adaptation to Learner Levels and Teaching Contexts

The Poetic Translation Mediation Cycle can be adapted to different teaching contexts. In a short classroom activity, the teacher may use only selected stages: interpretive reading, draft translation, and reflective commentary. In a longer lesson, all seven stages can be included. In a project-based course, students may prepare revised translations, commentaries, and comparative presentations.

The model can also be adapted for different learner levels. At lower levels, students may translate only key images, short lines, or selected phrases. At intermediate levels, they may translate stanzas and write short commentaries. At advanced levels, they may compare multiple published translations, analyze strategies, and produce more developed reflective essays.

A plurilingual perspective is also relevant. Learners do not need to treat their first language as an obstacle. Instead, they can use their full linguistic repertoire to compare meanings, test alternatives, and understand how languages organize poetic experience differently. In this sense, poetic translation can help learners develop a more flexible and comparative awareness of language, consistent with the mediation-oriented logic of the CEFR Companion Volume (Council of Europe, 2020).

6. Discussion

The Poetic Translation Mediation Cycle should be understood as a conceptual contribution to the intersection of pedagogical translation, mediation, poetry pedagogy, and reflective writing. Its value lies not in presenting poetic translation as a new classroom technique, but in reorganizing existing pedagogical and theoretical concerns into a coherent model.

First, the model contributes to pedagogical translation by specifying the distinct nature of poetic translation. Previous scholarship has argued that translation should not be automatically rejected because of its association with the grammar-translation method (Cook, 2010; Laviosa, 2014). This article extends that argument by showing that poetic translation is not merely a more difficult version of ordinary translation. It requires learners to negotiate meaning, image, rhythm, ambiguity, tone, cultural reference, and aesthetic effect. In this sense, poetic translation makes the interpretive dimension of translation visible.

Second, the model contributes to mediation theory by applying the CEFR-based concept of mediation to poetry translation. When learners translate a poem, they do not merely transfer a text into another language. They mediate between poetic traditions, semantic layers, cultural associations, aesthetic effects, and target-language readers. The model also extends mediation into the learner's reflective process: Reflective Translation Commentary allows students to make their own decisions intelligible to teachers and peers.

Third, the model contributes to poetry and literature-based foreign language teaching. Poetry is often valued for cultural and aesthetic engagement, but it may remain an occasional literary activity if it is not pedagogically structured. The Poetic Translation Mediation Cycle treats poetry as a serious site of linguistic, interpretive, intercultural, and reflective work. Translation

intensifies interpretation because it requires learners to decide how meaning, tone, and effect can be recreated in another language. This is consistent with educational work showing that poetry translation can generate literary awareness and creative engagement (Beauvais, 2019; Brookman & Robinson, 2016).

Fourth, the model contributes to reflective writing by proposing Reflective Translation Commentary as a classroom tool. Reflective writing has often been used to support metacognitive awareness (Knospe, 2018; Wärnsby et al., 2021), but its role in poetic translation pedagogy has not been sufficiently developed. In the proposed model, reflection is not a general personal response. It is a focused explanation of translation decisions: what was preserved, changed, lost, compensated for, and intended for the target reader.

The theoretical significance of the model lies in its integrative character. It does not claim that contextual orientation, close reading, drafting, reflection, or revision are new practices in themselves. The originality lies in bringing them together within a mediation-based framework specifically designed for poetic translation in foreign language teaching. In this way, the model offers a structured answer to the gap identified earlier in the article.

7. Limitations and Future Research

The argument developed in this article has several limitations. Since the article proposes a conceptual and pedagogical framework, it does not provide empirical evidence about the effectiveness of the Poetic Translation Mediation Cycle in actual classroom settings. It does not analyze learner translations, reflective commentaries, classroom observations, interviews, test scores, or assessment results. Therefore, it cannot claim that the model improves learners' interpretive reading, writing ability, translation competence, intercultural awareness, or metacognitive development.

Future research should test the model in real teaching contexts. Qualitative studies may analyze students' translation drafts and reflective commentaries to understand how learners make mediation decisions. Classroom observations may show how students discuss alternative translations and how teachers scaffold interpretation. Interviews may reveal how learners perceive poetry translation tasks. Mixed-methods studies may examine whether repeated use of the cycle supports vocabulary depth, interpretive reading, reflective writing, or translation strategy awareness.

One important area for future research is Reflective Translation Commentary. Future studies should investigate whether students focus mainly on vocabulary or also discuss imagery, tone, ambiguity, rhythm, and cultural meaning; whether they can identify what is lost or transformed in translation; and whether commentary quality improves after repeated practice. Previous research on translation commentary and self-reflection offers a useful starting point for designing such studies (Shei, 2005; Shih, 2018; Pietrzak, 2019).

The model also needs to be examined across language pairs, poetic traditions, and learner levels. Translating classical Persian poetry into Azerbaijani or Turkish may involve issues of shared cultural memory, Sufi terminology, metaphorical convention, and historically connected literary traditions. Translating the same poetry into English may create different challenges related to cultural distance, symbolic density, rhythm, and untranslatable concepts. Therefore, future research should examine which stages of the model are widely useful and which require local adaptation.

Finally, teacher preparation and assessment require further attention. Teachers need to guide literary interpretation, explain translation as decision-making, support reflective writing, manage discussion of multiple versions, and assess both translation products and commentaries. Future work should develop sample lesson plans, rubrics, reflective prompts, annotated poetry translation tasks, and model student commentaries.

8. Conclusion

This article addressed a conceptual gap in foreign language teaching. Pedagogical translation has increasingly challenged the exclusion of translation from language classrooms. CEFR-based mediation has provided a broader framework for understanding language users as social agents who make meaning accessible across linguistic and cultural boundaries. Poetry pedagogy has shown that literary texts can support interpretation, aesthetic awareness, and cultural engagement. Reflective writing has demonstrated the value of making learners' thinking visible. However, these areas have not been sufficiently integrated into a single model explaining how poetic translation can function as cross-linguistic mediation.

To respond to this gap, the article adopted an integrative conceptual review based on theory synthesis and model construction. The result is the Poetic Translation Mediation Cycle, a seven-stage pedagogical model consisting of contextual orientation, interpretive reading, lexical-semantic mapping, draft translation, mediation decision-making, reflective translation commentary, and revision through discussion.

The central argument of the article is that poetic translation should be understood as cross-linguistic mediation. A learner translating a poem does not simply replace source-language words with target-language words. The learner negotiates images, tones, ambiguities, cultural associations, aesthetic effects, and reader expectations. In this sense, poetic translation is not a secondary activity that follows comprehension. It is a continuation of interpretation through another language.

The model's main contribution is its process-oriented view of poetic translation. The final translated text is not treated as the only evidence of learning. Equally important are the learner's interpretive reading, mediation decisions, reflective commentary, and revisions. This shift allows teachers to evaluate not only whether a translation is accurate, but also how the learner understood the poem, what problems were recognized, which choices were made, and how those choices were justified.

At the same time, the argument must remain limited. The Poetic Translation Mediation Cycle is not presented as an empirically proven method. The article does not claim that the model automatically improves learners' reading, writing, translation competence, or intercultural awareness. Its contribution is conceptual: it clarifies a neglected intersection in the literature and offers a structured model for future pedagogical design and empirical research.

In conclusion, poetic translation should not be understood as a return to the grammar-translation method. Nor should it be treated merely as an occasional literary exercise. Properly scaffolded, it can become a mediation-based pedagogy of interpretation, reflection, and cross-linguistic meaning-making. The Poetic Translation Mediation Cycle provides a conceptual foundation for such a pedagogy and opens a path for future research on the role of poetic translation in foreign language teaching.

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А.БАЙТҰРСЫНҰЛЫ МЫСАЛДАРЫН ОҚЫТУДЫҢ ЕРЕКШЕЛІКТЕРІ

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XX ғасырдың басында қазақ халқы аса ірі қоғамдық-саяси өзгерістермен қатар ауқымды рухани жаңғыруларды да бастан кешті. Ұлттық мәдениет пен әдебиеттің, білім мен ғылымның туын көтерген, жұртшылықтың санасына демократиялық ойлар сіңіріп, алға жетелеуге ұмтылған зиялы топ қалыптасты. Халықтың зердесіне сәуле түсіріп, санасын оятқан осы топтың рухани көсемі Ахмет Байтұрсынов еді. Қазақ ауыз әдебиетінің зерттелуі А.Байтұрсынов пен Х.Досмұхамедовтан бастау алары сөзсіз. Аталмыш ғалымдардың ауыз әдебиеті жайлы алғашқы пікір-пайымдаулары кейінгі фольклорист-зерттеушілерге сара жол салды. Осы орайда аталған ғалымдардың назарынан тыс қалмаған мысал жанры да ауыз әдебиетінен бастау алғандығына көз жеткізуге болады. Әрине, фольклорды зерттеп, жанрлық жағы сараланған еңбектерде көбінесе мысал жанры қалыс қалып жатады, дегенмен мысал жеке түр ретінде қарастырылмаса да, ол жайында азды-көпті пікірлер бар. «Мысал - айтылатын өнегелі ойды тұспалдап жеткізетін, көбіне өлең түрінде келетін сюжетті, шағын көлемді көркем шығарма» [1, 36] деген анықтамаға ие мысалдың түп төркіні хайуанаттар туралы тұспалды мағынасы бар ертегі, қысқа әңгімелер нұсқаларымен жалғасып жатыр. Бұның қаншалықты дәлелді екенін қазақ ғалымдарының осы жанрға байланысты ой-пікірлерімен нақтылай түсейік.

Қазақ әдебиетінің көшбасшысы, ұлы ғалым Ахмет Байтұрсынов қазақ фольклорын сұрыптап, саралауда мысал жанрын назардан тыс қалдырмай, біраз ой толғап, анықтама береді. Ғалым жалпы ауыз әдебиетін жұмсалыуына қарай екіге бөледі: сауықтама; сарындама. Сарындаманы үшке бөледі: салт сөзі; ғұрып сөзі; қалып сөзі: Мысалдарды ғалым салт жолымен айтылатын сөздер тобына жатқыза отырып, мынадай анықтама келтіреді: «Адамның ғамалын, мінезін, құлқын жанды, жансыз нәрселер арқылы салт-санасына сәйкес көрсетіп өнегелеу мысалдау болады» [1, 37]. Сонымен қатар ғалымның біз үшін маңызды ескертуі де бар: мысалдар көбінесе хайуандар шыққан ертегілерден алынады. Ондай ертегілерде хайуандарға адамша тіл бітіріп, адамша мінездеп, іс еткізіп, түрлі өнеге боларлық сипаттанған. Одан әрі ғалым пікірі келесідей: «Мысалда аңдар, құстар, хайуанаттар, өсімдіктер іс-әрекеті, мінезі арқылы адам бойындағы мінді, кемшілікті тұспалдап, әжуә күлкі етеді... Осындай шағын көлемді, оқиғалы, адамға сабақ болатын тағылымдық шығарманы мысал дейді» [1, 37], - деп түйіндей түседі. Орыстың ұлы сыншысы В.Г.Белинский бұл жанрды: «Сатираға суғарылған поэзияның нағыз ерекше жанры» десе [1, 300], академик З.Қабдолов «Мысал адамгершілік мұқтажыңын өтеу мақсатында жанр ретінде әдебиет арнасына тоғысты», - дейді [2, 300]. С.И. Радцигтың «Көне грек әдебиетінің тарихы» атты оқулығында мысалға мынадай түсініктеме берілген: «Мысал – көне халық ауыз әдебиетінің жанры болып есептеледі. Себебі, мысалдардың мазмұнында хайуанаттар эпосының сарқыны сақталып қалған. Дегенмен тарихи тұрғыдан алғанда мысал жанры

күнделікті өмірдегі келеңсіз жағдайлар мен адамгершілік, ізгілік мәселесін насихаттауға арналған» [3, 300].

Ал, академик Зейнолла Қабдолов мысал жанры турасында мынандай пікір ұстанған: «Мысал- эпостық шығармалардың ішіндегі ең қысқа түрі. Әрқашан сатиралық сипатты, көбіне аң, хайуанат, кейде зат түрлері жазылады да сол арқылы адам бойындағы мін, әлеуметтік ортадағы кемшілік, күлкіге, келекейге, мазаққа айналдырып, сықақпен саналады. Мазмұны бүкпелі болғанымен, идеясыз, астарсыз, ашық, тура, тілі мірдің оғындай өткір, шымшыма, шымыр келеді. Ежелгі Грециядағы аты шулы Эзоп (б.э.б. VIғ.) шығармаларын өз алдына қойғанда, мысал көне дүниеден күні бүгінге дейін көбіне өлеңмен жазылып келеді: Италияда Федр, Францияда Лафонтен, Германияда Геллерт, Англияда Мур, Россияда Крылов, қазақта Абай – бәрі солай жазған. Біздің тұсымыздағы мысалшылардан Сергей Михалков пен Асқар Тоқмағамбетовты бөліп айтуға болады», - дейді [3, 312]. Кейіннен жарық көрген доцент М.М. Иманғазиновтың «Антика әдебиеті» атты еңбегінде автор: «Мысал - әріден келе жатқан, эпостың шағын да өткір жанры. Мысал жанры көне дәуірден біздің заманымызға дейінгі әлемнің іргелі ақын жазушыларының назарында болған, қызықты форма, ұғымды идея, халық тұрмысына ет жақын суреттеулерге толы әдеби жанр» [4, 251] деген тұжырымдама ұсынады. Десек те, ауыз әдебиетін оқытуда мысал жанры қарастырылмай келеді. Бұл жөнінде Ш.Ыбыраев былайша жазады: «Шынын айту керек, қазақ ауыз әдебиетіне арналған зерттеулер мен оқулықтарда айтыс пен шешендік сөздерден басқа аты аталып, ел танығаны жеті сегіз жанрлар болса, ол Еуропа халықтарының фольклорында кездесетіндері. Ал мұның сыртында аты аталмай, аталса да қатарға кірмей, күні бүгінге дейін халық жадында сақталып келген ондаған жанрлар мен жанрлық түрлердің не зерттеушілер, не жинаушылар тарапынан ілтипат көрмей келгенін немен түсіндіруге болады?» [4, 424].

Фольклортанушы осылай дей келе, ауыз әдебиетіндегі зерттелмей келе жатқан жанрдың бірі мысал екендігін атап көрсетеді де, қазақ ауыз әдебиетін жіктеудің жаңа түрлерін ұсынады: салтқа қатысты фольклор; салтқа қатыссыз фольклор. Салтқа қатыссыз фольклорды әрі қарай рим цифрларымен атап көрсетеді. II. Эпикалық прозалық жанрлар; III. Эпикалық жанрлар; IV. Кіші жанрлар; V. Шешендік сөздер; VI. Мысал. Ғалым Ш.Ыбыраев осылайша мысал жанрын ауыз әдебиетінің өзге де түрлерімен қатар қойып, бөлек топтайды. Сонымен қатар ол мысалды бұрын соңды кездеспеген жаңаша түрде жіктеуді ұсынады: А. Мысал (мысал өлеңдер, мысал сөз, мысал айтыс). Ә. Апалог. Б. Тәмсіл [5, 424]. Ғалымның бұл дәлелді тұжырымдары мысал жайындағы ұғымымызды кеңейте түседі. Міне, осы бағытта мысалдың түрлерін анықтап, оларды жинастырып, топтастыру, жанрлық ерекшеліктерін айқындау шын мәнінде зерделі зерттеуді күтетіні анық. Жоғарыдағы қос ғалымның ауыз әдебиетін жіктеуі бір-бірімен бағыттас, үндес келеді. Тек басты айырмашылық жанрлық атауларда сияқты. Ахмет Байтұрсынұлының сауықтама (барша сауық үшін айтылатын сөздер) деп отырғаны Ш.Ыбыраев еңбегінде салтқа қатысты фольклор деп аталса, сарындама салтқа қатыссыз фольклор, яғни «жұртта келе жатқан салт сарынмен айтылатын сөздер». Екі ғалым да мысал жанрын соңғы топқа жатқызады. Мысал жайында сөз қозғау барысында жанрдың шығу тегі қандай?, қалай қалыптасқан?, қайдан бастау алады? деген сұрақтар туады. Ахмет Байтұрсынұлының бұл орайда: «Арнайы әдебиеттегі мысалдар былай шыққан: «...алғашқы адамдар басқа мақұлықтардан ұзап жарымаған. Олар түрлі табиғат, түрлі тәсілмен тіршілік ететіндерін көріп, олар да адамша ойлайды, сөйлеседі, кеңеседі, бірін бірі аңдиды, арбайды деп білген... Сондықтан адамның ісін әңгіме қылған сияқты, олардың да істерін әңгіме қылған. Одан хайуандар турасындағы ертегілер шыққан. Онан бері келе, хайуандар тіршілік еткенмен нақ адамша ойласып, сөйлесіп, кеңес етпейтіндігіне көз жеткендігінен кейін мақұлықтар турасындағы ертегілер өтірікке саналып, бірте бірте жоғалып, тек мысалдар қалған» [6, 40], - деген тұжырымын негізге аламыз. Мәселен, «Сыртандар» ертегісінде

адамға жерік болған жалмауыз қасқыр біреудің жалғыз баласын аңдиды. Баланың әкешесі, ауыл аймағы қатты сасады. Сол кезде бала өзімен бір күнде туған тұлпарына мініп, қасқырдан қаша жөнеледі. «Құтқарам» деп тұлпар тартады: «Қайтсе де жеймін», деп жалмауыз қасқыр қуады. Осы тұста адамның досы тұлпар мен қасқырдың сырттаны жарысқа түседі. Сол жерде иттің сырттандары қасқырға қарсы ұмтылады, қасқырды өлтіреді [7, 26]. Мұнда жалмауыз қасқыр адам баласына қастық ойлаушы мол жауыздықтың бейнесінде алынса, ит пен жылқы жақсы жақтарынан дәріптеледі. Бергі заманда шығарылған халық ертегілерінде хайуанаттар бұрынғы керемет бейнесінде алынбай, жаңа кейіпте, реалистік болмысқа байланысты алынады. Осы ретте хайуанаттар жайы екі түрде алынып, қазақ ертегілеріне қосылады. Онда хайуанаттардың бір тобы (төрт түлік мал, үй хайуанаттары) шаруашылыққа келтіретін пайдасы, атқаратын қызметімен суреттеледі. Хайуанаттардың екінші тобы (жыртқыш аңдар) адам баласына жасаған жауыздығы, қаскүнемдігімен бейнеленеді. Бұл соңғысы уақыт өте келе халықтық сатираға айналып, сол арқылы қоғамдық жайлар, үстемдік еткен қауымның жағымсыз қылықтары әңгімеленеді; бұлар халықтың ащы мысқылы, келеке-күлкісі түрінде келеді; таптық тартыс, күрес жайы сөз болады. Мұны біз «Алтын сақа», «Тепең көк», «Бозінген», «Жақсылық пен жамандық» т.б. ертегілерден көре аламыз. Сонымен қатар, «Қотыр торғай» ертегісінде кекшілдікті, бірбеткейлікті, араға іріткі салуды меңзесе, «Мақта қыз бен мысық» ертегісінің жасөспірімдерге беретін тағылымы мол. Халық ертегісінде жыртқыш аңдардың әрқайсысына лайықты мінездеме береді. Арыстан - асқан күштің, зорлықтың, қасқыр - қомағайлық пен қорқаулықтың иесі болып кейіптеледі. Ал түлкі - айла мен аярлықтың, бірді бірге соғып, пайдасын тауып жүрген қу, өзінен басқаға дұшпандық жасаушы, сырттай дос, іштей қас болып келеді. Айналасындағы аң атаулыны алдаушы да, есек таратып күндеуші де, жоқ жерде пәле бастаушы да - түлкі. Бұлармен қатар, қазақ ертегілерінде о жарлық, аңқаулық кескінімен аю жүреді. Жұрттың бәріне мазақ, күлкі ретінде маймыл қатысады. Мәселен, «Маймыл мен түлкі», «Түлкі мен бөдене», «Түлкі, тасбақа, кене», «Түлкі, аю, қойшы» т.б. ертегілер. Өзімізге таныс қазақ мысалдарында да түлкі - қулық, айлакерліктің, қасқыр - қатыгез, қарақшылықтың, мысық - жалқаулықтың, есек - ақымақтықтың т.б. қызметін атқарады. Шынында да, мысал жанры қазақ халқының ойлау өрісінің дамуымен, сана эволюциясымен тығыз байланысты, айналадағы тіршілік иелерін танып білумен қатар, олардың айрықша қасиеттерін айқындап, адамды бейнелеудегі олардың түрлі мінезін әрқилы іс-қылықтарын тұспалдап көрсетуде шебер пайдалана білген. Әрқашан сөзге ұста қазақ халқы осы мәндегі астарлы әңгіме тұғызып оған «мысал» деп айдар таққан. Осындай арғы тегі хайуанаттар жайлы ертегіден өрбіп, өріс алған мысал жанры көбінесе, нақтылай айтсақ, оның бір тармағы мысал ертегілер апалог деп зерттеушілер тарапынан анықтамаға ие болып жүр. XIX ғасырға дейін апалог және мысал бір-біріне синоним ретінде қолданылған. Апалог көбінесе қара сөзбен жазылады. Ішінара өлең сөздері кездескенімен, өлең түріндегі апалогтар біздің әдебиетімізде тек жазбаша түрде кең дамыған. Ал өлең үріндегі апалогтың жеке жанр ретінде толық қалыптасуын ғалым С.Қасқабасов «XIX-XX ғасыр әдебиетінің жедел дамуы мысал жанрын әдеби арнаға бағыттады» деп түсіндіреді [8].

Мысал - аллегориялық жанр. Айтылатын ой ашық берілмейді. Астармен, меңзеумен беріледі. Жануарлар әлемі, құс, өсімдік, тағы басқа мысалдар бас кейіпкер ретінде алынады. Өткір сын да, ащы сатира да, байсалды юмор, келемеж, мысқыл да осы мысал жанрында, әдебиеттегі оқу бағдарламасында мысалдар көбінесе оқытудың бастауыш буынында беріледі. Ең алдымен, мысал жанры, оның өзіндік ерекшелігі туралы әдеби-теориялық ұғымнан мағлұмат, түсінік берген жөн. Яғни мысалда ойдың ашықайқын берілмейтіні, жорамал, меңзеу астарлы түрде берілетіні, кекесін, мысқыл, әжуа, юмор, ащы сатира оның негізі көркемдік тәсілі екендігін оқушыларға әңгімелеу, баяндау әдісімен жеткізген дұрыс. Мысалдарды оқу, талдау барысында бұл түсініктерге қайта оралып, осы ұғымдарды

оқушыларды өзіне аңдатып, түйіндетіп отыру керек. Алдымен, әдеби-теориялық ұғым беру, оқушыларды оқығалы отырған көркем шығарма ерекшелігін аңдауларына, ары қарай оны талдау белсенділіктерін арттыруға жетелейді. Оқығалы отырған мысалды алдын ала үйде оқып келу тапсырылса, оның тиімділігі тіпті зор болмақ (мұғалім мысал жанры туралы кіріспе түсінікті сол тапсырманы беру алдында айтуы керек). Мұғалім ол үшін оқушыларға мынадай үлестірме-көмек нұсқау таратып, өз беттерімен оқу, түсіну, талдау жасауға жетелейді. Сабақты қызықты етіп өту үшін, жоғары сыныптың қабілетті оқушыларымен мысалды инсценировкалап, талдау алдында көрініс беріп, әншілердің айтуындағы «Бұлбұл әнін» де пайдаланса, артық емес. Мұндай сабақтарды әдеби-композициялық сабақтар деп атайды.

Жалпы, қай әдеби жанрда жазылған шығармаларды талдамасын, мұғалім сабақ еткелі отырған тақырып ерекшелігі, сынып ерекшелігіне назар аударып, сонан соң барып, пайдаланылатын көрнекілік, т.б. оқу жабдықтарын, әдіс-тәсілдерді, сабақ түрлерін үйлестіре, тиімді дегендерін сұрыптап ала білу керек. «Есек пен бұлбұл» сияқты барлық мысалдар көлемі жағынан тұжырымды, қысқа, айтар ойы жағынан қомақты, салмақты болып келеді, әрі жоғарыда айтқанымыздай, айтылмақ ой жасырын жатады. Оқуға жеңіл, әрі қысқа осындай мысалдар тез оқылады, ал, түп негізіндегі салмақты мәселелерді тез аңғару оңай емес. Мысалдың осы бір ерекшелігін ескере отырып, мұғалім оны сыныпта оқып, балаларға оқытып, практикалық тапсырмалар да беруге болады. «Есек пен бұлбұлды» мынадай бөлімдерге белуге болады:

I бөлім. «Жолықты бір бұлбұлға тоғайдағы» (Есектің бұлбұлға кездесуі).

II бөлім. «...бір сайрап берсең...» (есектің өтініші).

III бөлім. «Өнерге салды бұлбұл...» (Бұлбұл әні).

IV бөлім. «... сен біраз әтеш әнін үйрен...» (есектің ақылы).

V бөлім. Авторлық қорытынды: «...Құдайым бізді сақтасын...».

Осындай жұмыстарды алғашқы сабақтарда балалармен бірге орындап, оларға басшылық жасап, келесі мысалдарды оқушылардың тек өздігінен, жеке дара, мұғалім көмегінсіз талдауына ұсынуға болады. Акын стилі, көркемдік тәсілін талдауға да мысалдарды оқытуда ерекше көңіл бөлу керек. Ол үшін әр бөлімдегі (жоғарыда көрсетілген) акын тәсіліне назар аударған жөн.

Мысалы:

I бөлімде - авторлық баяндау, суреттеу;

II бөлімде - диалог, сұрақ;

III бөлімде - баяндау, суреттеу;

IV бөлімде - диалог, ақыл;

V бөлімде - авторлық қорытынды, шешім, ақыл-нақылдардың орын алатынын дәлелдеу дұрыс болып саналады. Үйге тапсырма балалардың сабақты қалай меңгергеніне байланысты беріледі. Жалпы қабілеттеріне әсер ету, білім дағдыларын жетілдіру мақсатында рөлге бөліп, жатқа мәнерлеп оқу, көрініс көрсету сияқты шығармашылық сипаттағы тапсырмалар беру аса тиімді болып келеді. Өдебиет сабағы ақыл-өнегеге, ғибратқа, даналыққа, имандылыққа, адамгершілік үлгілерге толы болу керек десек, мысал туындыларынан осының бәрін кездестіруге болады. Сондықтан осы «Есек пен бұлбұл» арқылы әділдікті, өнерді, кішіпейілділікті үлгі ете отырып, әділетсіздік, тұрпайылық, топастықтан жирендіру жұмыстарын жүргізу керек. Мысал жанрын оқытуда да оқушылардың таным белсенділігін арттыратын, әсіресе, әдеби тартысқа жетелейтін, іздендіру, зерттеу жұмыстарыша баулитын әдіс-тәсілдерді пайдалану тиімді болмақ. Мысалдың басты мақсаты – адам баласының бойына жақсы, ізгілікті қасиеттерді сіңіру, терең ғибрат пен тәлім өнеге беру. Курстық жұмыстың зерттеу мәселесіне айналған өзекті сұрақтардың бірі осы мысал жанрын таныту,

соның ішінде қазақ мысалшыларының бірі Ахмет Байтұрсыновтың мысал жанрындағы шығармаларын меңгертудің тиімді жолдарын саралау болып табылады. Мысалдар бастауыш мектеп және орта буын сыныптары оқушыларының ой-өрісін жетілдіріп, Отанын сүйуге, елін қорғауға, өнерді игеруге, жалпы адамгершіліктік құндылықтарды бойына сіңіруге септігін тигізеді. Сонымен қатар баланың сөздік қорын да молайтуда қызметі өте зор. Ал сөздік қоры мол, тілі дамыған бала – үздік оқушы, себебі жоғарыда аталғандар – жақсы үлгілердің негізі. Ой өрісі дамып, сөздік қоры молайған баланың айтар ойы да, істер ісі де өнегелі болмақ. Демек, бала тілін дамыту – қоғам дамыған сайын күнделікті қажеттілікке айнала беретін ең өзекті мәселелердің бірі. Оның үстіне еліміз егемендік алғалы бері мемлекеттік тілде сөйлеу соны оқыту әдістемесін жетілдіру, соның ішінде, бала тілінің дамуы мен сөздік қорының молаю мәселесі әдіскер ғалымдардың зерттеуінен түспей, назардан тыс қалмай жүрген мәселелердің бірі. Болмысқа танымдық қатынасты ояту мен тәрбиелеудің бір жолы – өмірді тікелей бақылаудан басқа танымдық әдебиеттерде жатыр. Бүгінгі күні оқытуға қойылып отырға талаптардың бірі – өмір шындығын балаларға халық ауызекі шығармашылығы арқылы көрсету, оның негізінде балалардың ой-өрісін, қиялын, эстетикалық және адамгершілік сезімдерін дамыта отырып, олардың халық шығармашылығына сүйіспеншілігін еңбек сүйгіштікке деген көзқарастарын арттыру болып табылады. Қазақ мысалдары соның ішінде, мысалдың атасы – Ахмет шығармаларының қазақ әдебиетінің баға жетпес қазынасы. Оның осы сияқты аса жоғары идеалық көркем қасиетін балалардың санасына жеткізу үшін бұлардың да өзіне лайық оқып үйрену жолдары әдіс амалдары бар. Мысалдарды балалардың сүйіп оқитын барлық ықылас ынтасы сүйсіне тыңдайтындығы – әбден текшелеп халықтың тапқыр ой-пікірлері жинақталып, әрі көркем, әрі жеңіл тілмен берілетіндігінде. Тәрбиенің басты құралы болып табылатын мысал жанрын, Ахмет мысалдарын меңгертудегі тиімді тәсілдер қазіргі таңда ақпараттық-коммуникативтік технологиялармен, деңгейлік тапсырмалар қолдану, салыстыру, кейіпкерлерге мінездеме беру, Венн диаграммасы, инсерт кестесі, топпен жұмыс жасау (ертегілер бойынша тапсырмалар), жұптық тапсырмалар орындату тағы басқа әдістермен жүзеге асырылуда. Ахмет мысалдарын меңгертуде баланың жас-психологиялық ерекшеліктері ғана ескерілмей, жанрлық ерекшеліктері де басты назарға алынады. Сонымен қатар атап өтер бір жайт мысалдарды меңгертуде қолданылатын әдіс-тәсілдердің сан алуандығы мұғалім шеберлігіне байланысты қолданысқа ие болады және толығып отырады, заман талабына сәйкес өзгерістермен сипатталады. Мысал жанрының танымдық мәні жоғары болып табылғандықтан, оларды оқытуда, атап айтқанда мысал жанрындағы шығармалардың мазмұнын меңгерткенде идеялық, тақырыптық, яғни көркемдік шындығына жете назар аударған жөн. Себебі, мысал бала дүниетанымын, өзіндік көзқарасын қалыптастырудың бірден-бір құралы болып табылады. Ахмет мысалдарын оқытуда шығарманы жете талдау оның меңгертудің нәтижелі құралы болып саналады. Мысалдың кейіпкерлерін салыстыру, баға беру, сипаттау, мінездеу, суретін салу, шығарма жазу, диалогтік оқыту, рөлге бөліп оқыту, көрініс қою, көрнекілік әдістерін молынан қолдану жетістіктерге жеткізеді деген қорытынды жасаймыз.

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Economic Sciences

THE TRANSFORMATION OF THE WELFARE STATE: INTERSECTORAL COOPERATION AS A STRATEGIC RESOURCE FOR SOCIAL DEVELOPMENT

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Abstract

This article examines the evolution of the welfare state concept and analyzes the changing roles of the state, business, and civil society in addressing contemporary social challenges. Particular attention is paid to the institutional mechanisms that facilitate intersectoral cooperation, including public-private partnerships, social contracting, social entrepreneurship, ESG-oriented practices, public consultations, and collaborative governance arrangements.

The findings indicate that the effectiveness of the contemporary welfare state depends not on the expansion of state intervention, but on the quality of intersectoral cooperation aimed at creating public value and addressing complex social challenges. Based on the analysis, a concentric model of intersectoral cooperation is proposed, conceptualizing cooperation as a strategic resource for welfare state development and explaining the relationship between institutional cooperation mechanisms and social development outcomes.

Keywords: welfare state, intersectoral cooperation, collaborative governance, public governance, public value, public-private partnership, social contracting, social entrepreneurship, ESG, civil society, human capital, quality of life, sustainable development.

Introduction

The development of the welfare state in the twenty-first century takes place within an increasingly complex social environment. Traditional social risks associated with poverty, unemployment, and social inequality are now accompanied by new challenges arising from digital transformation, changes in employment structures, demographic shifts, migration processes, environmental threats, and rising public expectations. As a result, social protection systems, healthcare institutions, educational organizations, and other components of the social sphere are experiencing growing pressure.

At the same time, governments face significant resource constraints resulting from the need to maintain fiscal sustainability while improving the efficiency of public spending. Under these circumstances, it has become increasingly evident that the state is no longer capable of addressing the full spectrum of social problems exclusively through traditional regulatory instruments and budgetary financing.

Contemporary social development trends indicate a gradual transition from a model of state paternalism toward a model based on the joint participation of the state, business, and civil society in addressing socially significant challenges. Whereas classical welfare state models

positioned the state as the principal producer and provider of public goods, contemporary approaches increasingly emphasize intersectoral cooperation based on partnership, resource coordination, and the distribution of responsibilities among key societal actors.

This transition is particularly important in the context of sustainable social development. Modern welfare states are expected not only to provide social guarantees but also to contribute to improvements in quality of life, human capital development, social resilience, and the achievement of sustainable development goals. Consequently, the effectiveness of the welfare state is determined less by the scale of government intervention and more by the ability of public institutions to create favorable conditions for constructive cooperation among business organizations, civil society institutions, and public authorities in the process of public value creation (Ansell & Gash, 2008; Emerson & Nabatchi, 2015).

Against this background, there is a growing need to reconsider traditional approaches to welfare state development and to examine contemporary mechanisms of intersectoral cooperation as a key condition for social sustainability and long-term societal development.

1. The Evolution of the Welfare State Concept: From State Paternalism to Collaborative Governance

The historical foundations of the welfare state are commonly associated with the social reforms initiated by Otto von Bismarck in the German Empire during the second half of the nineteenth century. The introduction of compulsory social insurance schemes covering illness, disability, and old age laid the institutional foundations of state social policy and established a new model of relations between the state and society. Within this framework, the state assumed primary responsibility for addressing social problems and maintaining social stability (Bismarck, 1881–1889).

The subsequent development of welfare state theory is closely connected with the work of William Beveridge. In his landmark report *Social Insurance and Allied Services* (1942), Beveridge proposed a universal system of social protection based on the principles of inclusiveness and equal access to social guarantees. Unlike the Bismarckian model, which relied primarily on insurance mechanisms, the Beveridge approach emphasized comprehensive social protection regardless of an individual's income level or employment status. The state was viewed as the central institution responsible for ensuring social security and minimum standards of well-being.

During the second half of the twentieth century, welfare state ideas gained widespread acceptance across Europe and North America. The expansion of social responsibilities was accompanied by the development of education systems, healthcare services, pension schemes, employment programs, and various forms of social assistance. Scholars of this period viewed the welfare state as a key instrument for promoting social justice, social integration, and the reduction of social inequalities (Marshall, 1950; Titmuss, 1958).

As a result, the classical welfare state model emerged, characterized by the dominant role of the state in the production and distribution of public goods. Government institutions became the primary actors responsible for identifying social problems, designing policy responses, financing social programs, and monitoring their implementation. Relations between the state and society were predominantly hierarchical, while citizens were largely perceived as recipients of social services and welfare benefits.

However, by the late twentieth century, researchers increasingly pointed to the limitations of the classical welfare state model. Growing public expenditures, demographic ageing, increasing pressure on social protection systems, and declining efficiency of traditional regulatory mechanisms generated concerns regarding the long-term sustainability of welfare arrangements (Mishra, 1984; Pierson, 1994).

Particularly significant was the increasing complexity of social challenges themselves. Whereas traditional social policy focused primarily on poverty reduction, employment, and social

protection, contemporary societies face a much broader range of issues, including digital inequality, migration, demographic ageing, environmental risks, social inclusion, and sustainable development. Addressing such challenges requires the integration of financial, organizational, informational, expert, and human resources that are no longer concentrated exclusively within the public sector.

Against this background, the very nature of public governance began to undergo substantial reconsideration. The traditional concept of *government*, based on hierarchical authority and the dominant role of the state, gradually gave way to the concept of *governance*, which emphasizes coordination among multiple actors involved in social development.

According to Pierre and Peters (2000), contemporary governance increasingly represents a process of negotiating interests and coordinating actions among diverse societal stakeholders, including public authorities, business organizations, and civil society institutions. In this context, effective governance is no longer associated exclusively with the state's capacity to command and control; rather, it depends on its ability to facilitate cooperation and mobilize collective resources for addressing public challenges.

These ideas were further developed within the framework of *collaborative governance*. Ansell and Gash (2008) argue that the effectiveness of contemporary governance depends on the ability of public institutions to organize constructive interaction among governmental and non-governmental actors in order to address socially significant issues. Similarly, Emerson and Nabatchi (2015) conceptualize collaborative governance as an institutionalized system of cooperation based on joint decision-making, shared responsibility, and the integration of resources aimed at achieving public outcomes.

The emergence of governance and collaborative governance approaches reflects a broader transformation in the understanding of social development. Social problems are no longer perceived as issues that can be solved exclusively through governmental action. Instead, they are increasingly viewed as complex challenges requiring coordinated efforts from multiple sectors of society.

As a result, the contemporary stage of welfare state development is characterized by a transition from state paternalism toward partnership-based governance. While the state continues to play a central role in ensuring social stability and protecting public interests, its functions are gradually shifting from the direct provision of social goods toward the coordination of intersectoral interaction. Business organizations and civil society institutions are no longer regarded as external actors operating alongside social policy; they have become integral participants in addressing social challenges and creating public value.

2. Intersectoral Cooperation as a Mechanism for the Development of the Contemporary Welfare State

2.1. The State as the Architect of Intersectoral Cooperation

Traditionally, the state has been regarded as the primary actor responsible for designing and implementing social policy. However, contemporary welfare state development demonstrates a significant transformation of this role.

Whereas the classical welfare state model concentrated major social functions within governmental institutions, contemporary practice increasingly reflects a shift toward coordination-based governance. The state continues to occupy a leading position within the social sphere, yet its principal function is no longer limited to the direct provision of services. Instead, it increasingly focuses on creating institutional conditions that facilitate cooperation among various actors involved in social development.

In this context, the state acts less as a direct provider of social goods and more as an architect of interaction among public authorities, business organizations, civil society institutions, and citizens. It establishes regulatory frameworks, formulates strategic priorities, develops

mechanisms for stakeholder engagement, and creates opportunities for non-state actors to participate in addressing public challenges (Pierre & Peters, 2000; Osborne, 2010).

Within the framework of *New Public Governance*, the effectiveness of public administration is evaluated not by the number of functions performed by governmental institutions but by their capacity to coordinate networks of actors and facilitate collaborative problem-solving. Consequently, the state increasingly moves away from a control-oriented model toward a partnership-oriented model based on cooperation, mutual responsibility, and shared commitment to public outcomes.

Therefore, the contemporary state should be understood as a key organizer of intersectoral cooperation, responsible for creating institutional environments that enable the integration of resources distributed across different sectors of society.

2.2. Business as a Strategic Partner in Social Development

The role of business in contemporary society extends far beyond the traditional pursuit of profit maximization. The growing importance of Corporate Social Responsibility (CSR) and ESG-oriented management practices reflects the expanding involvement of business organizations in addressing social and environmental challenges.

Historically, corporate engagement in social issues was largely limited to philanthropic activities and charitable initiatives. Today, however, social responsibility is increasingly integrated into long-term business strategies and sustainable development agendas (Carroll, 1991).

Particularly influential in this regard is the concept of *Creating Shared Value* developed by Porter and Kramer (2011). According to this approach, companies can simultaneously generate economic value and social value by incorporating solutions to societal challenges into their core business activities. Social problems are therefore not viewed as external constraints but as opportunities for innovation, competitiveness, and sustainable growth.

Modern companies actively participate in educational, environmental, social, and infrastructure projects; invest in human capital development; support social entrepreneurship; and implement ESG principles within corporate governance systems. As a result, business increasingly functions not as an external partner of social policy but as a full-fledged participant in promoting public well-being and sustainable social development.

2.3. Civil Society as a Source of Public Expertise and Social Participation

In increasingly complex social environments, civil society plays a critical role as a source of public expertise, social participation, and feedback. Civil society organizations contribute to identifying emerging social needs, articulating public interests, and facilitating citizen engagement in decision-making processes. Non-governmental organizations, professional associations, volunteer movements, expert communities, and public councils serve as important intermediaries between the state and society.

The significance of civil society extends beyond advocacy and representation. Contemporary governance increasingly relies on citizen participation as a mechanism for improving the quality and legitimacy of public decisions. Through continuous feedback, public authorities gain a deeper understanding of societal needs and are better equipped to adapt social policies to changing social conditions.

Putnam (2000) argues that the effectiveness of public institutions is closely linked to the level of social capital and citizens' capacity for collective action. Similarly, Fukuyama (1995) identifies trust as one of the most important resources of societal development. From this perspective, civil society should not be viewed merely as a mechanism of public oversight; rather, it represents an active participant in social development and public value creation.

Consequently, the contribution of civil society to welfare state development lies not only in monitoring government performance but also in facilitating social innovation, strengthening civic engagement, and enhancing the responsiveness of public institutions.

2.4. Trust as the Foundation of Intersectoral Cooperation

Although the state, business, and civil society perform distinct functions within contemporary societies, the effectiveness of their cooperation depends less on formal institutional arrangements than on the level of trust among participants.

Trust serves as a fundamental prerequisite for sustainable partnerships, reducing transaction costs, facilitating information exchange, and improving the effectiveness of collective action. In the absence of trust, cooperation tends to become formalized, decision-making quality declines, and opportunities for long-term collaboration become limited.

From this perspective, trust should be regarded as an independent resource of welfare state development. It enables the alignment of interests among diverse stakeholders and supports the emergence of a culture of shared responsibility for addressing social challenges (Fukuyama, 1995; OECD, 2023).

The importance of trust becomes particularly evident in the implementation of public-private partnerships, social contracting arrangements, public consultations, and other forms of intersectoral cooperation. The effectiveness of these mechanisms depends not only on legal frameworks and organizational structures but also on the willingness of participants to engage in open dialogue, mutual learning, and collaborative problem-solving.

Therefore, trust should be viewed as the institutional foundation of intersectoral cooperation and one of the key determinants of welfare state effectiveness in contemporary societies.

Interim Findings

The analysis conducted thus far demonstrates that the contemporary welfare state functions as a complex system of interaction among the state, business, and civil society. Each participant possesses unique resources and competencies that are essential for addressing socially significant challenges.

Under these conditions, the effectiveness of social policy is determined not by the scale of government intervention, but by the quality of intersectoral cooperation that enables resource integration, coordinated action, and the co-creation of public value.

The growing complexity of social challenges requires a transition from isolated sectoral approaches toward collaborative forms of governance. Consequently, intersectoral cooperation emerges as a strategic mechanism for ensuring social sustainability, promoting human capital development, and improving quality of life.

3. Institutional Mechanisms of Intersectoral Cooperation in Contemporary Welfare State Development

The recognition of intersectoral cooperation as a prerequisite for welfare state development raises an important question: **How is such cooperation implemented in practice?**

The contemporary welfare state cannot function solely through administrative regulation and public financing. The integration of resources distributed across different sectors of society requires institutional mechanisms capable of facilitating coordination, cooperation, and the joint creation of public value.

These mechanisms serve not merely as administrative tools but as institutional arrangements through which diverse actors are able to combine resources, share responsibilities, and collectively address complex social challenges.

3.1. Public–Private Partnerships as a Mechanism for Resource Integration

Public–private partnerships (PPPs) represent one of the most widely used mechanisms of intersectoral cooperation. In contemporary governance systems, PPPs are no longer viewed solely as instruments for attracting private investment into infrastructure projects; they increasingly function as mechanisms for integrating public and private resources in pursuit of social objectives (Hodge & Greve, 2007).

Unlike traditional models of public financing, PPP arrangements combine the financial capacity and managerial expertise of the private sector with the strategic resources and regulatory authority of the state. Such cooperation creates additional opportunities for the development of education, healthcare, social infrastructure, and other sectors that directly influence quality of life.

Particularly under conditions of fiscal constraints, PPPs contribute to improving the efficiency of social investments and promoting more effective use of public resources. However, their success depends on the alignment of interests among stakeholders and the establishment of long-term relationships based on mutual responsibility and trust.

3.2. Social Contracting as a Mechanism for Engaging Civil Society

Among contemporary mechanisms of intersectoral cooperation, social contracting occupies a particularly important position due to its capacity to institutionalize collaboration between public authorities and civil society organizations.

Unlike traditional models of public service provision, social contracting enables governments to involve non-governmental organizations in the design and implementation of social programs aimed at addressing specific societal needs. Through this mechanism, public authorities gain access not only to additional organizational resources but also to the practical expertise, local knowledge, and social networks accumulated by civil society institutions.

An important advantage of social contracting lies in its ability to increase the responsiveness and adaptability of social policy. Civil society organizations often possess a deeper understanding of the needs of specific communities and social groups, enabling more targeted and effective interventions. As a result, social contracting contributes to the diversification of service provision, the strengthening of citizen participation, and the enhancement of public value creation.

From a governance perspective, social contracting represents a transition from hierarchical public administration toward collaborative forms of social problem-solving. It reflects the growing recognition that social challenges cannot be effectively addressed through governmental action alone but require the active involvement of multiple societal actors.

3.3. Social Entrepreneurship as a Hybrid Mechanism of Social Innovation

One of the most dynamic forms of intersectoral cooperation is social entrepreneurship, which combines social objectives with entrepreneurial approaches to problem-solving.

Unlike traditional business models focused primarily on profit generation, social enterprises seek to create measurable social impact while maintaining financial sustainability. At the same time, social entrepreneurship differs from charitable activities because it relies on market-based mechanisms rather than continuous external support.

The growing importance of social entrepreneurship reflects broader transformations in contemporary welfare systems. As governments face increasing resource constraints and social problems become more complex, innovative approaches capable of combining economic efficiency with social responsibility become increasingly valuable.

Social enterprises contribute to job creation, social inclusion, community development, and the provision of services for vulnerable groups. More importantly, they demonstrate how social and economic goals can be pursued simultaneously, thereby challenging traditional distinctions between the public, private, and non-profit sectors.

Consequently, social entrepreneurship should be viewed as a hybrid institutional mechanism that facilitates cooperation among government agencies, business organizations, and civil society institutions while generating both social and economic value.

3.4. Public Consultations and Citizen Participation

The effectiveness of contemporary welfare states increasingly depends on the extent to which citizens are involved in public decision-making processes. Consequently, public consultations, stakeholder engagement mechanisms, and participatory governance practices have become integral components of modern governance systems.

Public consultations provide opportunities for governments to gather information, incorporate diverse perspectives, and identify potential risks before implementing policy decisions. Citizen participation contributes to improving policy legitimacy, increasing transparency, and strengthening public trust in governmental institutions.

Moreover, participatory mechanisms facilitate mutual learning among stakeholders and promote a culture of shared responsibility for social development. Rather than treating citizens solely as recipients of public services, contemporary governance approaches increasingly recognize them as active contributors to policy design and implementation.

In this regard, public consultations represent more than a procedural requirement; they constitute an institutional mechanism through which governments can enhance the quality, legitimacy, and sustainability of social policies.

3.5. Digital Transformation and Participation Platforms

The digital transformation of public governance has significantly expanded opportunities for intersectoral cooperation. Digital technologies enable more efficient communication among stakeholders, facilitate information exchange, and create new channels for citizen engagement.

Digital participation platforms, open government initiatives, online consultation mechanisms, and electronic service delivery systems contribute to increasing transparency and improving access to public decision-making processes. These technologies reduce barriers to participation and allow governments to engage larger and more diverse groups of stakeholders.

Beyond administrative efficiency, digitalization also strengthens the collaborative capacity of governance systems by enabling continuous interaction among public authorities, business organizations, and civil society institutions. Consequently, digital transformation should be regarded not only as a technological process but also as an institutional driver of intersectoral cooperation.

As social interactions increasingly occur within digital environments, participation platforms become important mechanisms for public value creation and collective problem-solving.

3.6. Public Governance as an Integrative Framework for Intersectoral Cooperation

The mechanisms discussed above should not be viewed as isolated instruments operating independently from one another. Rather, they constitute elements of a broader governance architecture that supports cooperation among multiple societal actors.

This perspective is reflected in the concept of *Public Governance*, which emphasizes networks, partnerships, and collaborative relationships as fundamental features of contemporary governance systems (Osborne, 2010). Within this framework, the state, business, and civil society are understood as interdependent participants engaged in the joint creation of public value.

The effectiveness of welfare state development is therefore determined not by the performance of individual actors in isolation but by the quality of interaction among them. Public-private partnerships, social contracting arrangements, social entrepreneurship initiatives, participatory mechanisms, and digital platforms all contribute to the emergence of governance systems capable of addressing complex social challenges through collective action.

From this perspective, intersectoral cooperation should not be considered merely an administrative tool. It represents a systemic governance approach through which diverse resources, competencies, and interests are integrated to achieve socially desirable outcomes.

The analysis of institutional mechanisms demonstrates that contemporary welfare state development increasingly depends on the ability to organize cooperation among the state, business, and civil society. Public-private partnerships, social contracting, social entrepreneurship, participatory governance mechanisms, and digital platforms create institutional conditions for resource integration, shared responsibility, and collective problem-solving.

These mechanisms do not simply improve the efficiency of social policy implementation. More fundamentally, they transform the very logic of welfare state development by shifting the

focus from state-centered intervention toward collaborative forms of governance based on partnership, trust, and public value creation.

4. A Concentric Model of Intersectoral Cooperation in Welfare State Development

The analysis conducted throughout this study demonstrates that contemporary welfare state development can no longer be adequately explained through traditional state-centered approaches. The increasing complexity of social challenges, the diversification of societal actors, and the growing importance of collaborative governance require a broader conceptual framework capable of explaining how different sectors contribute to social development.

To address this issue, a concentric model of intersectoral cooperation in welfare state development is proposed. The model conceptualizes welfare state development as a dynamic process of interaction among the state, business, and civil society, emphasizing the role of institutional cooperation mechanisms in generating socially significant outcomes (figure 1).

Unlike traditional approaches that focus primarily on the individual functions of governmental institutions, the proposed model highlights the quality of interaction among societal actors as the key determinant of welfare state effectiveness.

4.1. The Outer Layer: Key Actors of Social Development

The outer layer of the model consists of three principal actors involved in contemporary social development: the state, business, and civil society.

The state provides the institutional and regulatory framework necessary for social development. Its responsibilities include strategic planning, policy formulation, social protection, and the establishment of legal conditions that facilitate cooperation among societal actors.

Business contributes financial resources, managerial expertise, technological innovation, and investment capacity. Increasingly, business organizations also participate in addressing social and environmental challenges through corporate social responsibility initiatives, ESG-oriented strategies, and sustainable development programs.

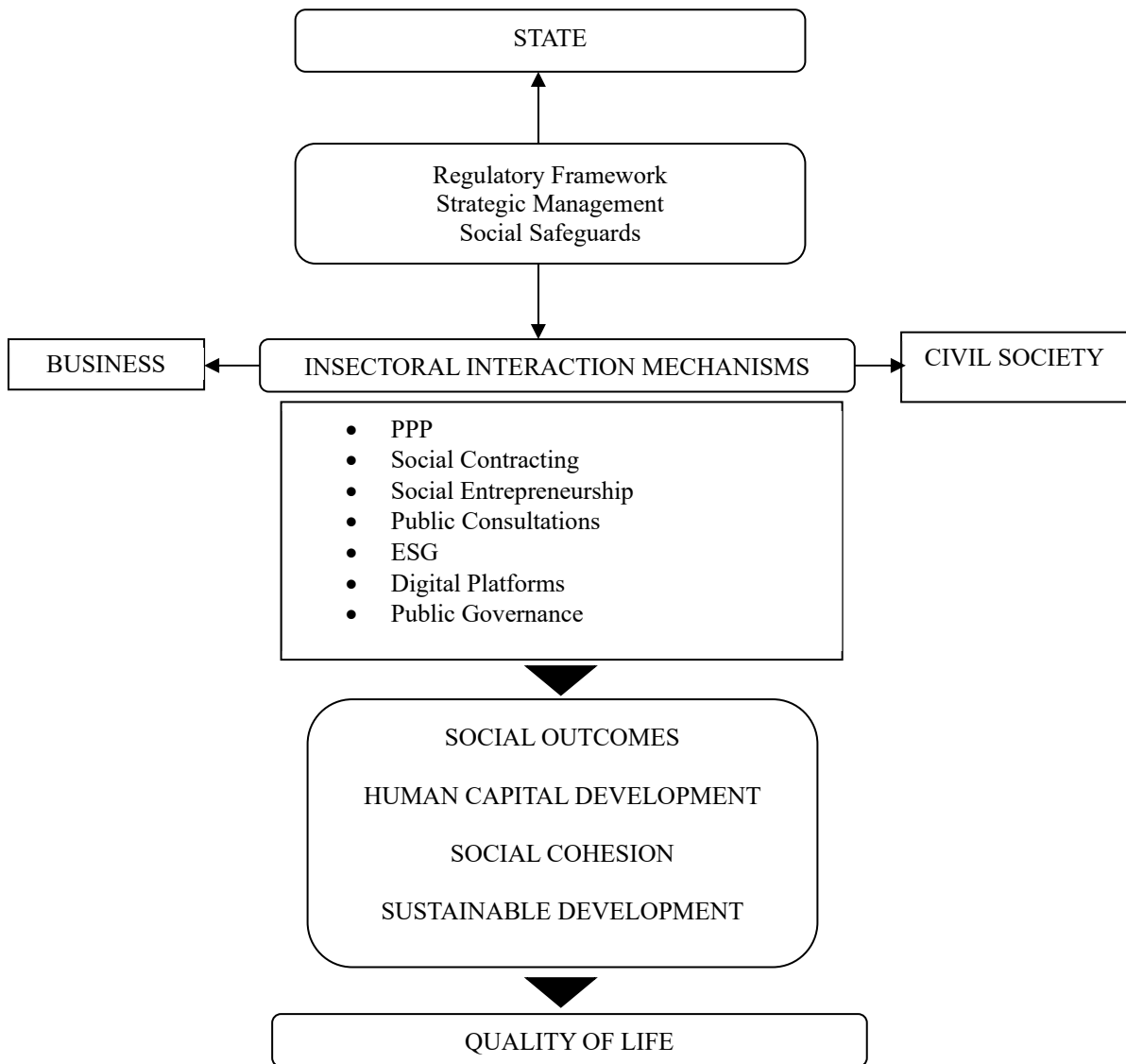


Figure 1 – Model of Intersectoral Cooperation in Welfare State Development

Civil society contributes public expertise, social participation, civic engagement, and feedback mechanisms. Through non-governmental organizations, volunteer movements, professional associations, and community initiatives, civil society helps identify emerging social needs and strengthens the responsiveness of governance systems.

Although these actors perform different functions, none of them possesses sufficient resources to address complex social challenges independently. Consequently, welfare state development depends on their ability to cooperate and coordinate their activities.

4.2. The Intermediate Layer: Institutional Mechanisms of Cooperation

The second layer of the model consists of institutional mechanisms that facilitate interaction among the state, business, and civil society.

These mechanisms include:

- public–private partnerships;
- social contracting;
- social entrepreneurship;
- public consultations;
- citizen participation mechanisms;
- digital participation platforms;

- collaborative governance arrangements.

The primary function of these mechanisms is to transform fragmented activities into coordinated efforts aimed at solving socially significant problems.

Through these institutional arrangements, resources that are dispersed across different sectors become integrated into a common framework of collective action. Cooperation therefore moves beyond occasional collaboration and becomes an institutionalized component of welfare state development.

The effectiveness of these mechanisms depends on transparency, accountability, stakeholder engagement, and, most importantly, trust among participants.

4.3. The Inner Layer: Social Development Outcomes

The third layer of the model represents the outcomes generated through intersectoral cooperation.

By combining resources and coordinating activities, societal actors contribute to the achievement of several interconnected objectives:

- human capital development;
- social cohesion;
- social resilience;
- sustainable development;
- improved effectiveness of social policy;
- public value creation.

These outcomes represent intermediate results that strengthen society's capacity to respond to existing and emerging challenges.

Importantly, the model assumes that social development outcomes emerge not from the isolated efforts of individual actors but from their ability to cooperate within a shared governance framework.

4.4. The Core of the Model: Quality of Life

At the center of the model lies quality of life, which serves as the ultimate objective of welfare state development.

Quality of life functions as an integrative indicator reflecting the effectiveness of interactions among the state, business, and civil society. Improvements in living standards, access to education and healthcare, social inclusion, human development, and overall well-being represent tangible manifestations of successful intersectoral cooperation.

The placement of quality of life at the center of the model reflects the fundamental assumption that welfare state development should ultimately be evaluated according to its impact on people's lives rather than solely by the volume of public spending or the number of social programs implemented.

Discussion

The proposed concentric model offers a conceptual framework for understanding contemporary welfare state development under conditions of increasing social complexity. It demonstrates that social development is no longer determined exclusively by governmental action but by the ability of diverse societal actors to cooperate through institutionalized mechanisms of interaction.

The model also highlights the importance of moving beyond traditional state-centered approaches toward governance arrangements based on partnership, shared responsibility, and public value creation.

Consequently, welfare state effectiveness should be assessed not only through the performance of public institutions but also through the quality of relationships that connect the state, business, and civil society within a broader system of collaborative governance.

Conclusion

The transformation of the welfare state represents one of the most significant developments in contemporary public governance. The increasing complexity of social challenges, the diversification of societal actors, and the growing demand for effective solutions have exposed the limitations of traditional state-centered approaches to social development.

The analysis conducted in this study demonstrates that welfare state development has evolved from a model based on state paternalism toward a model characterized by cooperation, partnership, and shared responsibility among the state, business, and civil society.

The study has shown that contemporary welfare state effectiveness depends on the ability to mobilize and coordinate resources distributed across different sectors of society. In this context, intersectoral cooperation emerges as a key mechanism for integrating diverse competencies, fostering collective action, and generating public value.

A central contribution of this study is the proposed concentric model of intersectoral cooperation, which conceptualizes welfare state development as a dynamic system of interaction among the state, business, and civil society. The model illustrates how institutional cooperation mechanisms contribute to the achievement of social development outcomes and ultimately to improvements in quality of life.

The findings suggest that the future of welfare state development depends not on increasing the scale of governmental intervention, but on improving the quality of cooperation among societal actors. Sustainable social development increasingly requires governance systems capable of fostering partnership, building trust, coordinating resources, and promoting collective responsibility for addressing public challenges.

Intersectoral cooperation should be viewed not merely as a governance mechanism, but as a strategic resource for welfare state development.

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AZƏRBAYCAN ƏRAZISİNDƏN KEÇƏN BEYNƏLXALQ NƏQLİYYAT DƏHLİZLƏRİNİN İQTİSADI TƏSİRİNİN QIYMƏTLƏNDİRİLMƏSİ VƏ İNKİŞAF PERSPEKTİVLƏRİ

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Xülasə: Bu tədqiqat Azərbaycan ərazisindən keçən beynəlxalq nəqliyyat dəhlizlərinin — Orta Dəhliz və Şimal-Cənub dəhlizinin — milli iqtisadiyyata çoxşaxəli təsirini araşdırır. Ölkənin Avropa ilə Asiya arasındakı strateji coğrafi mövqeyindən irəli gələn tranzit üstünlükləri, infrastruktur inkişafı, yeni iş yerlərinin yaranması və regional sosial-iqtisadi canlanma baxımından qiymətləndirilir. Eyni zamanda dövlət siyasəti, institusional mexanizmlər və rəqəmsal idarəetmə vasitələrinin dəhliz rəqabət qabiliyyətinə töhfəsi müzakirə olunur.

Açar sözlər: *nəqliyyat dəhlizi, tranzit iqtisadiyyatı, Orta Dəhliz, Şimal-Cənub dəhlizi, logistika infrastrukturunu, regional inkişaf, Azərbaycan*

Abstract: This study examines the multifaceted economic impact of international transport corridors passing through Azerbaijan — namely the Middle Corridor and the North-South Corridor — on the national economy. The country's strategic geographical position between Europe and Asia is assessed in terms of transit advantages, infrastructure development, employment generation, and regional socio-economic revitalization. The contribution of state policy, institutional mechanisms, and digital management tools to corridor competitiveness is also discussed.

Keywords: *transport corridor, transit economy, Middle Corridor, North-South Corridor, logistics infrastructure, regional development, Azerbaijan*

Giriş

Qlobal ticarət axınlarının genişləndiyi və beynəlxalq iqtisadi inteqrasiyanın dərinləşdiyi müasir şəraitdə nəqliyyat-logistika sistemlərinin strateji əhəmiyyəti durmadan artmaqdadır. Nəqliyyat dəhlizləri artıq təkcə yük daşıma vasitəsi kimi deyil, ölkələrin iqtisadi rəqabət qabiliyyətini müəyyən edən başlıca amillərdən biri kimi dəyərləndirilir [6, s.14–17]. Bu kontekstdə Azərbaycanın Qərblə Şərqi birləşdirən coğrafi qovşaqda yerləşməsi ölkəyə bənzərsiz tranzit imkanları bəxş edir. Azərbaycan Dövlət Statistika Komitəsinin məlumatlarına əsasən, son on ildə ölkə ərazisindən keçən yük dövriyyəsi ardıcıl artım meyli nümayiş etdirməkdədir [1, s.87–89].

Orta Dəhlizin iqtisadi əhəmiyyəti. Şərq-Qərb istiqamətli Orta Dəhliz Çin, Mərkəzi Asiya və Cənubi Qafqaz ölkələrini Avropa bazarlarına bağlayan alternativ marşrut kimi getdikcə daha böyük strateji əhəmiyyət kəsb edir. Ənənəvi şimal marşrutlarına nisbətən daha qısa tranzit müddəti, siyasi sabitlik üstünlüyü və dəniz-dəmir yolu kombinasiyası ilə seçilən bu dəhliz Azərbaycana tranzit gəlirlərinin artırılması, xarici investisiyaların cəlb edilməsi və müasir logistika infrastrukturunun formalaşdırılması baxımından ciddi perspektivlər açır [7, s.34–38]. Bakı Beynəlxalq Dəniz Ticarət Limanının müasirləşdirilməsi və Bakı-Tbilisi-Qars dəmir yolu xəttinin istifadəyə verilməsi bu strategiyanın əyani nümunəsidir [4, s.61–64].

Şimal-Cənub dəhlizinin strateji rolu. Rusiya, Azərbaycan və İrani birləşdirərək Hindistana qədər uzanan Şimal-Cənub Beynəlxalq Nəqliyyat Dəhlizi (INSTC) ölkəyə fərqli bir strateji dəyər qazandırır. Bu marşrut Azərbaycanı Cənubi Asiya ilə Şimali Avropa arasındakı ticarət zəncirinin ayrılmaz həlqəsinə çevirir, yük dövriyyəsini artırır və dəmir yolu infrastrukturunun modernləşdirilməsini sürətləndirir [3, s.102–107]. Ekspert qiymətləndirmələrinə görə, INSTC-nin tam işə salınması Azərbaycanın tranzit gəlirlərini əhəmiyyətli dərəcədə artırmaqla yanaşı, əlaqəli sənaye sahələrinin də canlanmasına zəmin yaradacaqdır [3, s.109–111].

Geniş spektrli iqtisadi təsirlər. Beynəlxalq nəqliyyat dəhlizlərinin müsbət iqtisadi təsiri yalnız tranzit ödənişləri ilə məhdudlaşmır. Limanlar, dəmir yolu qovşaqları və logistika mərkəzləri ətrafında yeni iş yerlərinin yaranması, regionlarda yaşam standartlarının yüksəlməsi və kiçik-orta müəssisələrin inkişafı üçün əlverişli mühitin formalaşması — bunların hamısı dəhlizlərin dolayı, lakin mühüm iqtisadi nəticələridir [2, s.78–82]. Nəqliyyat infrastrukturuna edilən investisiyaların multiplikator effekti bir sıra əlaqədar sektorlara — tikinti, energetika, xidmət sektoru — da müsbət impuls verir [6, s.49–52].

Dövlət siyasəti və institusional çərçivə. Azərbaycan hökuməti tranzit potensialının reallaşdırılması üçün məqsədyönlü siyasət həyata keçirir. İkitərəfli və çoxtərəfli nəqliyyat sazişlərinin bağlanması, gömrük prosedurlarının sadələşdirilməsi və rəqəmsal idarəetmə sistemlərinin tətbiqi ölkəni beynəlxalq yük daşıyıcıları üçün daha rəqabətqabiliyyətli tranzit məkanına çevirir [5, s.116–120]. Dövlət-özəl sektor tərəfdaşlığı modeli infrastruktur layihələrinin maliyyələşdirilməsini şaxələndirməyə imkan verir [5, s.122–124].

Nəticə

Azərbaycan ərazisindən keçən beynəlxalq nəqliyyat dəhlizləri ölkənin iqtisadi diversifikasiyasında, tranzit gəlirlərinin artırılmasında və regional inkişafın stimullaşdırılmasında həlledici rol oynayır. Coğrafi üstünlükdən maksimum fayda əldə etmək üçün institusional islahatların dərinləşdirilməsi, rəqəmsal texnologiyaların tətbiqi və beynəlxalq əməkdaşlığın genişləndirilməsi zəruri şərtlərdir [7, s.41–43]. Dəhlizlər üzrə hərtərəfli iqtisadi qiymətləndirmənin aparılması davamlı inkişaf strategiyalarının elmi əsaslarla formalaşdırılması baxımından prioritet vəzifə olaraq qalır [4, s.68–70].

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BEYNƏLXALQ NƏQLİYYAT DƏHLİZLƏRİNİN AZƏRBAYCANIN XARİCİ TİCARƏTİNƏ TƏSİRİ: QIYMƏTLƏNDİRMƏ VƏ İNKİŞAF PERSPEKTİVLƏRİ

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Xülasə: Bu tədqiqat beynəlxalq nəqliyyat dəhlizlərinin Azərbaycanın xarici ticarət göstəricilərinə çoxşaxəli təsirini araşdırır. Ölkənin ixrac potensialının genişlənməsinə, idxal xərclərinin azaldılmasına və ticarət ortaqları ilə əlaqələrin dərinləşməsinə nəqliyyat infrastrukturunun töhfəsi qiymətləndirilir. Logistika xərclərinin azalması, çatdırılma müddətlərinin qısalması və bazarlara çıxış imkanlarının genişlənməsi baxımından dəhlizlərin xarici ticarət rəqabət qabiliyyətinə müsbət təsiri əsaslandırılır.

Açar sözlər: *xarici ticarət, nəqliyyat dəhlizi, ixrac potensialı, logistika xərcləri, ticarət rəqabət qabiliyyəti, Azərbaycan, tranzit*

Abstract: This study examines the multifaceted impact of international transport corridors on Azerbaijan's foreign trade indicators. The contribution of transport infrastructure to expanding the country's export potential, reducing import costs, and deepening relations with trade partners is assessed. The positive effect of corridors on foreign trade competitiveness is substantiated in terms of reduced logistics costs, shorter delivery times, and expanded market access.

Keywords: *foreign trade, transport corridor, export potential, logistics costs, trade competitiveness, Azerbaijan, transit*

Giriş

Beynəlxalq ticarətin həcmnin sürətlə artdığı müasir dövrdə nəqliyyat infrastrukturunu ölkələrin xarici iqtisadi fəallığını birbaşa müəyyən edən amilə çevrilmişdir. Yüksək logistika xərcləri və uzun çatdırılma müddətləri ixracatçıların rəqabət qabiliyyətini zəiflədərək ticarət axınlarını əhəmiyyətli dərəcədə azalda bilər [7, s.22–25]. Bu baxımdan Azərbaycanın ərazisindən keçən beynəlxalq nəqliyyat dəhlizlərinin inkişafı ölkənin xarici ticarət imkanlarının genişləndirilməsinin əsas rıçaqlarından birinə çevrilmişdir. Dövlət Statistika Komitəsinin məlumatlarına görə, nəqliyyat infrastrukturuna yönəldilən investisiyaların artımı ixrac həcmnin müsbət dinamikası ilə paralel inkişaf etmişdir [2, s.104–107].

Nəqliyyat xərclərinin xarici ticarətə təsiri. Logistika xərclərinin azaldılması ixracatçıların beynəlxalq bazarlarda rəqabət üstünlüyü qazanmasında mühüm rol oynayır. Tədqiqatlar göstərir ki, nəqliyyat xərclərinin 10 faiz azalması ixrac həcmi orta hesabla 5–8 faiz artırır [7, s.38–41]. Azərbaycanda Orta Dəhliz və Şimal-Cənub dəhlizinin inkişafı nəticəsində əmtəə dövriyyəsinin maya dəyəri aşağı düşmüş, bu da yerli istehsalçıların xarici bazarlara çıxışını asanlaşdırmışdır [5, s.47–50].

İxrac potensialının genişlənməsi. Nəqliyyat dəhlizlərinin inkişafı Azərbaycanın yeni bazarlara çıxış imkanlarını əhəmiyyətli dərəcədə artırmışdır. Dəhlizlər vasitəsilə Mərkəzi Asiya, Avropa və Cənubi Asiya bazarlarına çatdırılma müddətlərinin qısalması Azərbaycan mallarının həmin bazarlarda rəqabət qabiliyyətini yüksəltmişdir [1, s.63–67]. Qeyri-neft sektoru üzrə ixrac göstəricilərinin artımında nəqliyyat infrastrukturunun təkmilləşdirilməsinin xüsusi payı müşahidə

olunur; bu tendensiya xüsusilə kənd təsərrüfatı məhsulları və yüngül sənaye malları üzrə aydın nəzərə çarpır [3, s.88–92].

Ticarət balansına struktural təsir. Nəqliyyat dəhlizlərinin inkişafı yalnız ixracı deyil, idxal əməliyyatlarının səmərəliliyini də artırır. Çatdırılma müddətlərinin qısalması istehsalçı müəssisələrin xammal və yarımfabrikat ehtiyatlarını azaltmasına, dövriyyə vəsaitlərinin daha səmərəli istifadəsinə zəmin yaradır [4, s.79–83]. Uzunmüddətli perspektivdə isə tranzit gəlirləri ilə ixrac gəlirlərinin birlikdə artması ölkənin ticarət balansının müsbətləşməsinə töhfə verir [3, s.95–97].

Ticarət şəbəkəsinin genişlənməsi və diversifikasiyası. Beynəlxalq nəqliyyat dəhlizləri Azərbaycanın ticarət ortaqlarının coğrafiyasını genişləndirir. Dəhlizlər vasitəsilə Azərbaycan ilə əlaqələr quran ölkələrin sayının artması ixrac bazarlarının diversifikasiyasına imkan verir, bu da xarici ticarətin tək bir bazara asılılığını azaldır [6, s.31–35]. Ticarət şəbəkəsinin genişlənməsi həmçinin xarici birbaşa investisiyaların cəlb olunmasını stimullaşdıraraq iqtisadi inkişaf üçün əlavə resurs bazası yaradır [1, s.71–74].

Nəticə

Beynəlxalq nəqliyyat dəhlizlərinin inkişafı Azərbaycanın xarici ticarət potensialının reallaşdırılmasında strateji əhəmiyyət daşıyır. Logistika xərclərinin azalması, çatdırılma müddətlərinin qısalması və yeni bazarlara çıxış imkanlarının genişlənməsi ölkənin ixrac rəqabət qabiliyyətini yüksəltməklə yanaşı, ticarət balansına da müsbət təsir göstərir [4, s.86–88]. İxrac bazarlarının coğrafi diversifikasiyası isə iqtisadi sabitliyin möhkəmləndirilməsi baxımından xüsusi əhəmiyyət kəsb edir. Bu sahədə institusional mexanizmlərin gücləndirilməsi və rəqəmsal logistika həllərinin tətbiqi perspektivdə dəhlizlərin xarici ticarətə töhfəsini daha da artıracaqdır [6, s.38–40].

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İSTEHSAL MÜƏSSİSƏLƏRİNDƏ MALİYYƏ ÖHDƏLİKLƏRİNİN UÇOTU: BEYNƏLXALQ STANDARTLARIN TƏTBİQİ MƏSƏLƏLƏRİ

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Xülasə

Müasir iqtisadi şəraitdə müəssisələrin maliyyə fəaliyyətinin düzgün uçotunun təşkili və maliyyə hesabatlarının beynəlxalq standartlara uyğun hazırlanması xüsusi əhəmiyyət kəsb edir. Maliyyə öhdəliklərinin uçotu müəssisələrin maliyyə sabitliyinin təmin olunması və maliyyə hesabatlarının şəffaflığının artırılması baxımından mühüm rol oynayır. Məqalədə istehsal müəssisələrində maliyyə öhdəliklərinin uçotunun beynəlxalq maliyyə hesabatı standartlarına uyğun təşkili məsələləri araşdırılmışdır. Tədqiqat zamanı maliyyə öhdəliklərinin tanınması, qiymətləndirilməsi və maliyyə hesabatlarında əks etdirilməsi prinsipləri təhlil edilmişdir. Eyni zamanda IFRS 9 standartının maliyyə öhdəliklərinin uçotunda tətbiqi xüsusiyyətləri və mövcud problemlər araşdırılmışdır.

Açar sözlər: *maliyyə öhdəlikləri, mühasibat uçotu, beynəlxalq maliyyə hesabatı standartları, IFRS 9, istehsal müəssisələri, maliyyə hesabatı.*

ACCOUNTING OF FINANCIAL LIABILITIES IN MANUFACTURING ENTERPRISES: ISSUES OF APPLICATION OF INTERNATIONAL STANDARDS

Abstract

In modern economic conditions, the correct organization of the accounting of enterprises' financial activities and the preparation of financial statements in accordance with international standards are of particular importance. The accounting of financial liabilities plays a crucial role in ensuring the financial stability of enterprises and increasing the transparency of financial statements. This article investigates the issues of organizing the accounting of financial liabilities in manufacturing enterprises in accordance with International Financial Reporting Standards. During the research, the principles of recognition, measurement, and presentation of financial liabilities in financial statements were analyzed. At the same time, the application characteristics and existing challenges of the IFRS 9 standard in the accounting of financial liabilities were explored. While the application of international standards ensures transparency, objectivity, and higher quality of financial reporting, manufacturing enterprises still face certain challenges, such as the adaptation of the accounting system, the professional qualification level of accountants, and the modernization of information systems.

Keywords: *financial liabilities, accounting, International Financial Reporting Standards (IFRS), IFRS 9, manufacturing enterprises, financial statements.*

УЧЕТ ФИНАНСОВЫХ ОБЯЗАТЕЛЬСТВ НА ПРОИЗВОДСТВЕННЫХ ПРЕДПРИЯТИЯХ: ВОПРОСЫ ПРИМЕНЕНИЯ МЕЖДУНАРОДНЫХ СТАНДАРТОВ

Аннотация

В современных экономических условиях особое значение приобретают правильная организация учета финансовой деятельности предприятий и подготовка финансовой

отчетности в соответствии с международными стандартами. Учет финансовых обязательств играет важную роль в обеспечении финансовой стабильности предприятий и повышении прозрачности финансовой отчетности. В статье исследованы вопросы организации учета финансовых обязательств на производственных предприятиях в соответствии с международными стандартами финансовой отчетности. В ходе исследования были проанализированы принципы признания, оценки и отражения финансовых обязательств в финансовой отчетности. В то же время были изучены особенности применения стандарта IFRS 9 в учете финансовых обязательств и существующие проблемы. Хотя внедрение международных стандартов обеспечивает прозрачность, объективность и повышение качества финансовой отчетности, производственные предприятия все еще сталкиваются с определенными трудностями, такими как адаптация системы бухгалтерского учета, уровень профессиональной подготовки бухгалтеров и модернизация информационных систем.

Ключевые слова: *финансовые обязательства, бухгалтерский учет, международные стандарты финансовой отчетности (МСФО), IFRS 9 (МСФО 9), производственные предприятия, финансовая отчетность.*

1. Giriş

Müasir iqtisadi münasibətlər şəraitində müəssisələrin maliyyə fəaliyyətinin idarə olunmasında maliyyə öhdəliklərinin uçotu mühüm əhəmiyyət kəsb edir. Maliyyə öhdəlikləri müəssisənin digər təsərrüfat subyektləri qarşısında yaranan borc və öhdəliklərini əks etdirir və müəssisənin maliyyə vəziyyətinin qiymətləndirilməsində əsas göstəricilərdən biri hesab olunur. Maliyyə öhdəlikləri dedikdə müəssisənin kredit təşkilatları, təchizatçılar, investorlar və digər iqtisadi subyektlər qarşısında yaranan borc öhdəlikləri başa düşülür. Bu öhdəliklər müəssisənin maliyyə hesabatlarında düzgün şəkildə əks etdirilməli və onların uçotu mövcud mühasibat uçotu standartlarına uyğun aparılmalıdır.

Müasir dövrdə qlobal iqtisadi inteqrasiyanın güclənməsi mühasibat uçotu sistemində beynəlxalq standartların tətbiqini zəruri etmişdir. Bu baxımdan beynəlxalq maliyyə hesabatı standartları (BMHS) müəssisələrin maliyyə hesabatlarının beynəlxalq səviyyədə müqayisə olunmasını təmin edən mühüm normativ bazanı təşkil edir. BMHS sistemində maliyyə öhdəliklərinin uçotu əsasən IFRS 9 "Maliyyə alətləri" standartı ilə tənzimlənir. Bu standart maliyyə öhdəliklərinin tanınması, ilkin qiymətləndirilməsi və sonrakı ölçülməsi qaydalarını müəyyən edir. IFRS 9 standartına əsasən maliyyə öhdəlikləri ilkin olaraq ədalətli dəyər üzrə tanınır və sonrakı mərhələdə amortizasiya olunmuş dəyər üzrə qiymətləndirilir.

İstehsal müəssisələrində maliyyə öhdəlikləri əsasən bank kreditləri, kreditor borcları, istiqraz öhdəlikləri və digər maliyyə borcları formasında meydana çıxır. Bu öhdəliklərin düzgün uçotu müəssisələrin maliyyə sabitliyinin təmin olunmasına və maliyyə risklərinin azaldılmasına imkan yaradır. Beynəlxalq standartların tətbiqi maliyyə öhdəliklərinin uçotunun daha şəffaf və obyektiv aparılmasına şərait yaradır. Bu standartların tətbiqi nəticəsində müəssisələrin maliyyə hesabatlarının keyfiyyəti artır, investorlara və digər maraqlı tərəflərə daha etibarlı məlumat təqdim olunur.

Lakin istehsal müəssisələrində beynəlxalq standartların tətbiqi zamanı müəyyən çətinliklər də mövcuddur. Bu çətinliklər əsasən mühasibat uçotu sisteminin uyğunlaşdırılması, mühasiblərin peşəkar hazırlıq səviyyəsi və informasiya sistemlərinin modernləşdirilməsi ilə bağlıdır.

State Management of the Tourism Sector as a Socio-Economic System in the Republic of Kazakhstan

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Abstract

The tourism sector in the Republic of Kazakhstan functions as a multifaceted socio-economic system, shaped by deliberate state policies aimed at economic diversification, regional balance, cultural heritage preservation, and environmental sustainability. This article offers a comprehensive examination of the institutional architecture, strategic policy instruments, governance mechanisms, and empirical performance outcomes within Kazakhstan's tourism management framework. Drawing on official statistical data, program evaluations, and comparative international benchmarks, the analysis highlights the sector's growing contributions to gross domestic product (GDP), employment, foreign exchange earnings, and social cohesion. At the same time, it critically addresses structural challenges such as infrastructure bottlenecks, human capital deficits, regulatory fragmentation, and sustainability pressures amid rapid visitor growth. The study traces the state's evolving role from direct administrative control toward a more facilitative, collaborative model emphasizing public-private partnerships (PPPs) and community engagement. Policy recommendations focus on digital transformation, skills enhancement, integrated planning, and alignment with Sustainable Development Goals (SDGs) to bolster Kazakhstan's international competitiveness.

Keywords: tourism governance, Kazakhstan, socio-economic system, sustainable tourism development, state regulation, economic diversification, public-private partnerships, ecotourism.

Introduction

In resource-dependent economies undergoing structural transformation, tourism frequently serves as a strategic lever for diversification, job creation, and inclusive regional development. The Republic of Kazakhstan, the largest landlocked country in the world, possesses a rich mosaic of natural landscapes—including the majestic Altai and Tien Shan mountains, the vast steppes, the Caspian Sea coastline—and a profound cultural heritage linked to the ancient Silk Road. These assets position the nation as a promising destination, yet realizing this potential has required sustained state intervention since independence in 1991.

State management of tourism constitutes a complex, open socio-economic system characterized by interdependent subsystems: institutional-regulatory, economic-financial, socio-cultural, infrastructural, and ecological. This system operates through continuous feedback loops between policy inputs, stakeholder interactions, and measurable outputs such as tourist flows, revenue generation, and employment levels. The government's objectives extend beyond purely economic metrics to encompass social equity, cultural continuity, and environmental stewardship, aligning with broader national strategies such as "Kazakhstan 2050" and the United Nations Sustainable Development Goals.

Major policy milestones include the adoption of the State Program for the Development of the Tourism Industry for 2019–2025, which established ambitious targets for visitor numbers,

investment, and GDP contribution. Subsequent updates and complementary initiatives—such as visa liberalization, the Neo Nomad visa, and ecotourism standards—reflect adaptive responses to global trends and domestic realities. This article provides a systematic analysis of the system’s architecture, performance dynamics, and persistent implementation gaps, offering evidence-based insights for further optimization.

Theoretical Framework: Tourism Governance as a Socio-Economic System

Systems theory, particularly as articulated in the works of von Bertalanffy and subsequent applications in tourism studies, conceptualizes the sector as a dynamic entity with inputs (policies, investments, natural and cultural resources), processes (regulation, service delivery, marketing), outputs (economic value added, employment, visitor satisfaction), and feedback mechanisms (monitoring, adaptation). In transitional post-Soviet contexts like Kazakhstan, governance has evolved from highly centralized Soviet-era models toward hybrid arrangements incorporating market incentives and multi-stakeholder collaboration.

This framework integrates elements of the experience economy (Pine & Gilmore), foresight methodologies, and resilience thinking, especially pertinent after the COVID-19 disruptions. Kazakhstan’s approach also aligns with global sustainability paradigms, notably the Global Sustainable Tourism Council (GSTC) criteria and SDG targets related to decent work (SDG 8), innovation and infrastructure (SDG 9), and responsible consumption (SDG 12). The state’s coordinating role remains pivotal in balancing supply-side development with demand-side promotion while mitigating negative externalities.

Institutional and Legal Framework

The central coordinating body is the Ministry of Tourism and Sports of the Republic of Kazakhstan, supported by the national company “Kazakh Tourism” (established 2017) acting as the primary Destination Management Organization (DMO). Regional akimats implement localized policies, while inter-ministerial coordination involves the Ministries of Ecology, Investment and Development, and others. Frequent institutional shifts—six changes in oversight between 1993 and 2017—have historically challenged policy continuity, though recent stabilization has improved outcomes.

Key instruments include:

The State Program for Tourism Industry Development 2019–2025, targeting an increase in inbound visitors to 3 million (total visitors up to 9 million), domestic tourists to 8 million, employment growth to 650,000, and substantial investment expansion. Many targets were adjusted and partially met amid post-pandemic recovery.

Visa reforms: expansion of visa-free regimes, e-visa introduction, and the Neo Nomad visa for digital nomads.

Economic incentives: preferential loans via the Damu Fund (6–10% rates), long-term tax exemptions (up to 25 years for priority projects), subsidies, and guarantees.

Sustainability measures: updates to the Environmental Code and the new national ecotourism standard ST RK (effective 2025), aligned with GSTC principles.

Public-private partnerships and special tourism-recreational zones complement these tools, fostering private investment while maintaining state oversight.

Socio-Economic Performance and Empirical Impact

Kazakhstan’s tourism sector has exhibited robust post-pandemic recovery. International arrivals reached approximately 15.3 million in 2024 (excluding certain categories), with strong growth continuing into 2025. Domestic tourism exceeded 10 million trips in 2024, approaching strategic benchmarks.

Economic contributions have strengthened. In 2025, the sector generated over \$1.3 billion in tax revenue (18% year-on-year increase), with foreign tourist spending at around \$2.9 billion and investments rising 33% to \$2.74 billion. Direct GDP contribution approached 2.5% in recent assessments, with total (direct + indirect) impacts estimated higher. Value added from tourism averaged 2,050.5 billion tenge over recent periods, peaking significantly in strong years.

Employment effects are notable: the sector supports hundreds of thousands of jobs, with projections reaching 800,000 by 2029, including new opportunities in rural agrotourism. Ancillary sectors—hospitality, transport, agriculture, and crafts—benefit through multiplier effects (e.g., tourist expenditure multipliers around 2.5–2.8 in specific national park studies).

Regional dynamics reveal concentration in key hubs: Almaty (nearly half of international visitors), Astana, Turkistan, and emerging areas like Akmola (Burabai). National parks and protected areas saw visitation surge from 1.3 million in 2019 to 2.8 million in 2024 and nearly 4 million in 2025—a 47% increase in the latter year. Popular sites include Burabai, Ile-Alatau, and Kolsai Lakes.

Digital tools such as the e-Qonaq registration system have improved data accuracy, addressing previous underreporting from informal accommodations.

Challenges in State Management and Implementation Gaps

Despite notable progress, several interrelated challenges persist. Infrastructure deficits—particularly roads, utilities, and quality accommodations in peripheral regions—remain a primary constraint. Major projects (e.g., Almaty Superski, Caspian Riviera, Astana Tourism District) signal commitment, yet execution often lags behind planning.

Human capital shortages manifest in limited skilled hospitality personnel, multilingual services, and digital competencies. Regulatory barriers, including bureaucratic permitting and fragmented inter-agency coordination, deter investors. Historical low budget execution rates (e.g., around 17% in certain program phases) underscore monitoring weaknesses.

Sustainability concerns have intensified with visitor growth. Rapid increases in national park attendance risk ecosystem degradation without adequate carrying capacity management. Marketing efforts, while improved through campaigns like “Kazakhstan. Very Nice!” and international events, still require stronger global digital positioning. Regional disparities exacerbate inequalities, with benefits disproportionately accruing to urban centers.

Comparative Analysis and Governance Effectiveness

Kazakhstan improved its ranking in the World Economic Forum’s Travel & Tourism Development Index to 52nd out of 119 in 2024 (up six places), reflecting gains in openness, investment, and policy environment. However, it continues to lag peers in infrastructure quality, price competitiveness, and business facilitation.

Strengths include political stability, natural endowments, and innovative instruments (ecotourism standards, visa reforms). Governance effectiveness has advanced via digitalization and PPPs, yet deeper stakeholder integration and policy continuity are needed. Case studies—such as the Almaty mountain cluster, Turkistan cultural sites, and Akmola natural areas—demonstrate both successes in multi-stakeholder planning and persistent local implementation gaps.

Case Studies of Regional Implementation

Almaty Mountain Cluster: Master plans integrating ski tourism, urban amenities, and environmental safeguards illustrate coordinated development, though service quality varies.

Akmola Region (Burabai and Kokshetau): High visitation to national parks highlights potential, but infrastructure and community benefit-sharing require enhancement.

Turkistan and Silk Road Routes: Cultural heritage investments have boosted arrivals, supporting local crafts and hospitality.

These examples underscore the necessity of place-based strategies tailored to specific resource profiles within the national system.

8. Recommendations for Systemic Optimization

To strengthen the socio-economic system, the following evidence-based measures are proposed:

Establish a unified national-regional coordination platform with real-time digital monitoring dashboards.

Streamline investment procedures through “one-stop” mechanisms and expanded green incentives.

Scale targeted vocational and higher education programs in partnership with international institutions.

Mandate comprehensive carrying capacity assessments and link tourism revenues to conservation funds.

Accelerate digital transformation, including AI-supported personalization and unified booking platforms.

Promote community-based tourism models to ensure inclusive benefits, particularly for rural and women-led enterprises.

Refine KPIs to incorporate SDG alignment, resilience indicators, and visitor experience metrics.

Deepen multilateral cooperation with UNWTO, UNDP, and global investors.

A comprehensive post-2025 national tourism master plan, grounded in independent audits and foresight exercises, should anchor the next development phase.

Conclusion

State management of the tourism sector in Kazakhstan exemplifies a socio-economic system in active transition—from centralized resource mobilization toward adaptive, collaborative governance attuned to sustainability and competitiveness imperatives. Empirical gains in visitor numbers, revenues, investments, and employment demonstrate the efficacy of strategic policy interventions. Nevertheless, bridging persistent implementation gaps through enhanced coordination, human capital investment, and environmental safeguards remains essential for unlocking the sector’s full potential.

Strategically located at the crossroads of Eurasia, endowed with unparalleled natural and cultural diversity, Kazakhstan is well-positioned to emerge as a leading tourism destination in Central Asia. Optimized governance will not only accelerate economic diversification and prosperity but also advance cultural dialogue, ecological balance, and social well-being across generations. Future research should focus on longitudinal impact evaluations and comparative governance models to further inform policy evolution.

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İkinci Qarabağ Müharibəsindən sonra daşınmaz əmlak və mülkiyyət hüquqlarının bərpası prosesi: problemlər və perspektivlər

The process of restoring real estate and property rights after the Second Karabakh War: challenges and prospects

Həmzəyev Səxavət Eldar oğlu

Abstract: Following the Second Karabakh War, the large-scale reconstruction and rehabilitation activities carried out in the liberated territories have created new opportunities for the development of the real estate sector in the Karabakh Economic Region. The reconstruction of residential areas, the implementation of modern urban planning principles, and the restoration of transportation and utility infrastructure have significantly contributed to the formation and growth of the regional real estate market. This article examines the main directions of real estate development in the Karabakh Economic Region, the key factors influencing this sector, and the role of state reconstruction programs and investment projects. Furthermore, the study analyzes the restoration of property rights, the return of displaced populations, the implementation of Smart City and Smart Village concepts, and the impact of socio-economic development on the real estate market. The findings indicate that the sustainable development of the real estate sector in the Karabakh Economic Region depends on the expansion of infrastructure projects, the improvement of the investment climate, and the adoption of modern management mechanisms.

Xülasə. İkinci Qarabağ müharibəsindən sonra azad edilmiş ərazilərdə genişmiqyaslı bərpa və yenidənqurma işlərinin həyata keçirilməsi Qarabağ iqtisadi zonasında daşınmaz əmlak sektorunun inkişafı üçün yeni imkanlar yaratmışdır. Regionda yaşayış məntəqələrinin yenidən qurulması, müasir şəhərsalma prinsiplərinin tətbiqi, nəqliyyat və kommunal infrastrukturun bərpası daşınmaz əmlak bazarının formalaşmasına və inkişafına mühüm təsir göstərir. Məqalədə Qarabağ iqtisadi zonasında daşınmaz əmlakın inkişaf istiqamətləri, bu sahəyə təsir edən əsas amillər, dövlət tərəfindən həyata keçirilən bərpa proqramları və investisiya layihələri təhlil edilir. Həmçinin mülkiyyət hüquqlarının bərpası, əhalinin geri qayıdışı, "Ağıllı şəhər" və "Ağıllı kənd" konsepsiyalarının tətbiqi, eləcə də regionun sosial-iqtisadi inkişafının daşınmaz əmlak bazarına təsiri araşdırılır. Tədqiqat nəticəsində müəyyən edilmişdir ki, Qarabağ iqtisadi zonasında daşınmaz əmlak sektorunun davamlı inkişafı üçün infrastruktur layihələrinin genişləndirilməsi, investisiya mühitinin təkmilləşdirilməsi və müasir idarəetmə mexanizmlərinin tətbiqi xüsusi əhəmiyyət kəsb edir.

Açar sözlər: Qarabağ iqtisadi zonası, daşınmaz əmlak, daşınmaz əmlak bazarı, şəhərsalma, yenidənqurma, Böyük Qayıdış, mülkiyyət hüquqları, investisiya mühiti, ağıllı şəhər, ağıllı kənd, regional inkişaf.

Keywords: Karabakh Economic Region, real estate, real estate market, urban planning, reconstruction, Great Return Program, property rights, investment climate, Smart City, Smart Village, regional development.

Giriş

Günümüzdə münaqişədən sonrakı dövrdə daşınmaz əmlakın bərpası və inkişafı iqtisadi dirçəlişin əsas istiqamətlərindən biri hesab olunur. İkinci Qarabağ müharibəsindən sonra azad edilmiş ərazilərdə genişmiqyaslı bərpa və yenidənqurma işlərinin həyata keçirilməsi daşınmaz əmlak sektorunun inkişafı üçün yeni imkanlar yaratmışdır. Müharibə nəticəsində yaşayış evlərinin, sosial infrastrukturun və istehsal obyektlərinin dağıdılması regionda əmlak münasibətlərinin yenidən formalaşdırılmasını zəruri etmişdir.

Qarabağ iqtisadi zonasında həyata keçirilən yenidənqurma layihələri, yeni yaşayış məntəqələrinin salınması, "Ağıllı şəhər" və "Ağıllı kənd" konsepsiyalarının tətbiqi, nəqliyyat və kommunal infrastrukturun bərpası daşınmaz əmlak bazarının inkişafına mühüm təsir göstərir. Eyni zamanda, məcburi köçkünlərin doğma yurdlarına qayıdışı, mülkiyyət hüquqlarının bərpası və investisiya mühitinin yaxşılaşdırılması regionda daşınmaz əmlak sektorunun perspektivlərini daha da genişləndirir.

Bu baxımdan Qarabağ iqtisadi zonasında daşınmaz əmlakın inkişaf istiqamətlərinin araşdırılması həm elmi, həm də praktiki cəhətdən aktualdır. Tədqiqatın əsas məqsədi regionda daşınmaz əmlak bazarının formalaşmasına təsir edən amillərin, mövcud problemlərin və gələcək inkişaf perspektivlərinin təhlil edilməsidir.

Əsas hissə

Münaqişədən sonrakı dövrdə daşınmaz əmlak hüquqlarının bərpası iqtisadi və sosial dirçəlişin əsas şərtlərindən biri hesab olunur. Qaçqınların və məcburi köçkünlərin mənzil, torpaq və digər əmlak üzərində hüquqlarının bərpası beynəlxalq hüququn əsas prinsiplərindən biridir. Yaşayış yerinə qayıtmaq, adekvat mənzilə sahib olmaq, mülkiyyət hüquqlarının qorunması və sərbəst hərəkət etmək hüququ münaqişədən zərər çəkmiş insanların sosial rifahının və təhlükəsizliyinin təmin edilməsində mühüm rol oynayır. Bu baxımdan daşınmaz əmlakın bərpası yalnız hüquqi məsələ deyil, həm də sosial sabitliyin və iqtisadi inkişafın vacib elementi kimi çıxış edir.

Müharibədən sonra daşınmaz əmlakın bərpası prosesində müxtəlif problemlər meydana çıxır. Ən ciddi çətinliklərdən biri torpaq sahələri və tikililərlə bağlı sənədlərin itirilməsi və ya ümumiyyətlə mövcud olmamasıdır. Bir çox hallarda torpaqlar və tikililər rəsmi qeydiyyatla alınmadığından onların hüquqi statusunu müəyyən etmək və sahibliyi sübut etmək çətinləşir. Bundan əlavə, əhalinin məcburi köçürülməsi, qeyri-rəsmi torpaq istifadəsi, torpaq mübahisələri və mülkiyyət hüquqları ilə bağlı qeyri-müəyyənliklər daşınmaz əmlak bazarının formalaşmasına və inkişafına mənfi təsir göstərir. Buna görə də mülkiyyət hüquqlarının bərpası və rəsmiləşdirilməsi regionun uzunmüddətli inkişafı üçün vacib şərtlərdən hesab olunur.

Qarabağda müharibədən sonra həyata keçirilən dövlət proqramlarının əsas istiqamətlərindən biri yeni mənzil fondunun yaradılması olmuşdur. Evsiz qalmış ailələrin mənzillə təmin edilməsi məqsədilə yeni yaşayış binalarının və yaşayış məhəllələrinin tikintisinə başlanılmışdır. Bu layihələr minlərlə ailənin mənzil şəraitinin yaxşılaşdırılmasına, yeni yaşayış məntəqələrinin formalaşdırılmasına və əhalinin doğma torpaqlarına qayıdışının sürətləndirilməsinə xidmət edir. Mənzil fondunun genişləndirilməsi yalnız sosial məqsədlərə deyil, eyni zamanda regionda daşınmaz əmlak bazarının formalaşmasına və investisiya aktivliyinin artmasına da müsbət təsir göstərir.

Daşınmaz əmlak sektorunun inkişafında müasir kadastr və qeydiyyat sisteminin yaradılması xüsusi əhəmiyyət daşıyır. Qeydiyyatla alınmış torpaq və tikililər üzrə məlumatların elektron bazada saxlanması əmlakın hüquqi statusunun müəyyənləşdirilməsini asanlaşdırır. Lakin qeyri-rəsmi istifadə olunan torpaq sahələri və qeydiyyatsız tikililər daşınmaz əmlakın idarə olunması və kompensasiya mexanizmlərinin tətbiqində ciddi çətinliklər yaradır. Buna görə də kadastr məlumatlarının yenilənməsi, mülkiyyət hüquqlarının rəsmiləşdirilməsi və daşınmaz əmlakın vahid informasiya bazasının formalaşdırılması prioritet istiqamətlərdən biri kimi qiymətləndirilir.

Qarabağ iqtisadi zonasında daşınmaz əmlakın inkişafı yalnız yeni yaşayış və kommersiya obyektlərinin tikintisi ilə məhdudlaşmır. Bu proses həmçinin mülkiyyət hüquqlarının bərpasını, torpaq münasibətlərinin tənzimlənməsini, müasir kadastr sisteminin formalaşdırılmasını, investisiya mühitinin yaxşılaşdırılmasını və əhalinin dayanıqlı məskunlaşmasının təmin edilməsini əhatə edir. Daşınmaz əmlak sektorunun inkişafı regionun sosial-iqtisadi dirçəlişinin mühüm istiqamətlərindən biri olmaqla yanaşı, Qarabağın uzunmüddətli iqtisadi inkişafı və investisiya cəlbediciliyinin artırılması üçün də əsas zəmin yaradır.

Birinci Qarabağ müharibəsindən sonra BMT-nin məlumatlarına əsasən Azərbaycan əhalisi arasında məcburi köçkünlərin ümumi sayı təxminən 750 min nəfər təşkil etmişdir. Bu göstəriciyə Qarabağın özündən, ona bitişik yeddi rayondan və Ermənistan ərazisindən köçkün düşmüş şəxslər daxil idi. 1990-cı illərin əvvəllərində həmin insanlar çadır şəhərciklərində, yataqxanalarda, inzibati binalarda və hətta istifadədən çıxarılmış vaqonlarda məskunlaşdırılmışdılar. Sonrakı dövrdə dövlət tərəfindən sosial mənzillərin tikintisinə başlanılmış, məcburi köçkünlərin mənzil şəraitinin yaxşılaşdırılması istiqamətində ardıcıl tədbirlər həyata keçirilmişdir.

İkinci Qarabağ müharibəsindən sonra isə dövlət siyasətinin əsas istiqamətlərindən biri “Böyük Qayıdış” proqramı çərçivəsində əhalinin doğma torpaqlarına geri dönüşünün təmin edilməsi olmuşdur. Aparılmış sorğular göstərir ki, məcburi köçkünlərin əhəmiyyətli hissəsi öz doğma yurdlarına qayıtmaq niyyətindədir. Bununla yanaşı, uzun illər ərzində formalaşmış yeni sosial və iqtisadi şərait, xüsusilə də gənc nəslin böyük şəhərlərdə məskunlaşması geri qayıdış prosesinə müəyyən təsirlər göstərir.

Qarabağa qayıdış prosesinin uğurla həyata keçirilməsi regionda daşınmaz əmlak sektorunun inkişafı üçün mühüm əhəmiyyət daşıyır. Yeni yaşayış məhəllələrinin salınması, fərdi evlərin və çoxmənzilli binaların tikintisi, sosial və kommunal infrastrukturun yaradılması daşınmaz əmlaka olan tələbatı artırır. Eyni zamanda, dövlət tərəfindən yalnız daimi məskunlaşmaq niyyətində olan vətəndaşların mənzillə təmin edilməsinin nəzərdə tutulması yaşayış fondunun səmərəli istifadəsinə və regionda dayanıqlı məskunlaşmanın formalaşmasına xidmət edir.

Əhalinin Qarabağa geri qayıdışı daşınmaz əmlak bazarının genişlənməsinə, yeni yaşayış sahələrinin yaradılmasına, tikinti sektorunun canlanmasına və regionun ümumi sosial-iqtisadi inkişafına mühüm töhfə verir.

2020-ci ildə ikinci Qarabağ müharibəsindən sonra Qarabağın azad edilmiş ərazilərində məskunlaşma və daşınmaz əmlakın bərpası məsələləri dövlət siyasətinin prioritet istiqamətlərindən birinə çevrilmişdir. Birinci Qarabağ müharibəsi nəticəsində yüz minlərlə insan doğma yurdlarını tərk etməyə məcbur olmuş, uzun illər ərzində ölkənin müxtəlif bölgələrində müvəqqəti yaşayış məntəqələrində məskunlaşmışdır. Müharibədən sonrakı dövrdə həyata keçirilən “Böyük Qayıdış” proqramı həmin əhalinin doğma torpaqlarına geri dönüşünü və normal yaşayış şəraitinin yaradılmasını nəzərdə tutur. Bu məqsədlə azad edilmiş ərazilərdə yeni yaşayış məhəllələrinin, fərdi evlərin, çoxmənzilli binaların, sosial obyektlərin və mühəndis-kommunikasiya infrastrukturunun qurulması istiqamətində genişmiqyaslı layihələr həyata keçirilir.

Daşınmaz əmlak sektorunun inkişafı baxımından əsas məsələlərdən biri mülkiyyət hüquqlarının bərpası və torpaq münasibətlərinin yenidən tənzimlənməsidir. Uzun illər ərzində istifadəsiz qalmış və ya dağıdılmış yaşayış məntəqələrinin yenidən qurulması üçün torpaq uçotu sisteminin təkmilləşdirilməsi, vahid kadastr məlumat bazasının yaradılması və daşınmaz əmlakın rəqəmsal qeydiyyatının aparılması mühüm əhəmiyyət daşıyır. Bununla yanaşı, yeni iqtisadi və sosial şəraitə uyğun olaraq müasir şəhərsalma prinsiplərinin tətbiqi, “Ağıllı şəhər” və “Ağıllı kənd” konsepsiyalarının reallaşdırılması regionda daşınmaz əmlak bazarının inkişafına yeni imkanlar yaradır.

Azad edilmiş ərazilərin bərpası yalnız yaşayış fondunun yaradılması ilə məhdudlaşmır. Regionda kənd təsərrüfatı, sənaye, xidmət və turizm sahələrinin inkişafı üçün əlverişli şərait formalaşdırılması da daşınmaz əmlak bazarına müsbət təsir göstərir. Yeni iş yerlərinin yaradılması,

iqtisadi aktivliyin artması və əhalinin geri qayıdışının sürətlənməsi nəticəsində yaşayış, kommersiya və sənaye təyinatlı daşınmaz əmlaka tələbatın artacağı gözlənilir. Bu baxımdan Qarabağ iqtisadi zonasında daşınmaz əmlak sektorunun inkişafı regionun ümumi sosial-iqtisadi dirçəlişinin əsas istiqamətlərindən biri hesab olunur.

Qarabağa qayıdış prosesi çərçivəsində məcburi köçkün ailələri tərəfindən itirilmiş yaşayış evləri və digər daşınmaz əmlak obyektləri barədə məlumatlar toplanır. Bu məqsədlə vətəndaşlardan onların müharibə nəticəsində itirdikləri evlər, torpaq sahələri və digər əmlaklar barədə məlumatlar təqdim etmələri tələb olunur. Mülkiyyət sənədlərinin itirilməsi hallarında həmin sənədlərin arxiv materialları və ya məhkəmə prosedurları vasitəsilə bərpası nəzərdə tutulur. Eyni zamanda mülkiyyət hüququnun təsdiqlənməsi üçün fotosəkillər, şahid ifadələri və digər sübut vasitələrindən də istifadə oluna bilər.

Daşınmaz əmlakın bərpası və yeni yaşayış məntəqələrinin yaradılması prosesində əsas məsələlərdən biri kompensasiya mexanizmlərinin formalaşdırılmasıdır. Uzun illər ərzində baş vermiş iqtisadi dəyişikliklər nəzərə alınmaqla itirilmiş əmlakın dəyərinin müəyyən edilməsi və adekvat kompensasiya mexanizmlərinin hazırlanması xüsusi əhəmiyyət kəsb edir. Bu istiqamətdə həyata keçirilən tədbirlər regionda daşınmaz əmlak bazarının inkişafına, investisiya mühitinin yaxşılaşdırılmasına və əhalinin doğma torpaqlarına qayıdışının sürətləndirilməsinə xidmət edir.

Nəticə

Qarabağda münaqişədən sonrakı dövrdə daşınmaz əmlakın bərpası və inkişafı yalnız yaşayış evlərinin yenidən tikilməsi ilə məhdudlaşmır. Bu proses həm də məcburi köçkünlərin geri qayıdışı, mülkiyyət hüquqlarının bərpası, sosial infrastrukturun qurulması və iqtisadi fəaliyyətin canlandırılması kimi kompleks məsələləri əhatə edir. Regionda uzunmüddətli və dayanıqlı məskunlaşmanın təmin olunması üçün yeni yaşayış məntəqələrinin yaradılması ilə yanaşı, məşğulluq imkanlarının artırılması, kənd təsərrüfatının inkişafı, nəqliyyat və kommunal infrastrukturun bərpası da mühüm əhəmiyyət kəsb edir.

Son illərdə Qarabağda genişmiqyaslı tikinti və yenidənqurma layihələri həyata keçirilsə də, daşınmaz əmlak bazarının tam formalaşması üçün bir sıra hüquqi və institusional problemlərin həlli tələb olunur. Mülkiyyət sənədlərinin itirilməsi, torpaq uçotu sisteminin yenidən qurulması, kadastr məlumatlarının dəqiqləşdirilməsi və kompensasiya mexanizmlərinin təkmilləşdirilməsi bu istiqamətdə əsas vəzifələr hesab edilir. Eyni zamanda, müharibədən sonrakı dövrdə formalaşmış yeni sosial və iqtisadi şərait əhalinin geri qayıdış prosesinə və daşınmaz əmlaka olan tələbatın strukturuna təsir göstərir.

Qarabağ iqtisadi zonasında həyata keçirilən bərpa layihələri regionun investisiya cəlbediciliyinin artırılmasına, yeni yaşayış və kommersiya obyektlərinin yaradılmasına, həmçinin müasir şəhərsalma prinsiplərinin tətbiqinə şərait yaradır. Bu baxımdan daşınmaz əmlak sektorunun inkişafı yalnız tikinti fəaliyyətinin genişlənməsi deyil, həm də regionun ümumi sosial-iqtisadi dirçəlişinin mühüm tərkib hissəsi kimi qiymətləndirilir. Bununla yanaşı, əhalinin gələcək yaşayış və sahibkarlıq fəaliyyətinin davamlılığının təmin olunması Qarabağda daşınmaz əmlak bazarının uzunmüddətli inkişaf perspektivlərini müəyyən edən əsas amillərdən biri hesab olunur.

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Қазақстан республикасының туризм саласындағы жобалық басқару

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Аннотация

Мақалада Қазақстан Республикасының Туризм саласындағы жобалық басқаруды қолданудың теориялық және практикалық аспектілері қарастырылған. Жобалық тәсілдің негізгі қағидаттары, оны туристік саланы мемлекеттік басқаруға енгізу ерекшеліктері, сондай-ақ туризмді дамытудың стратегиялық мақсаттарын іске асырудағы жобалық басқарудың рөлі зерттелді. Туристік жобаларды басқарудың қолданыстағы тетіктері талданды, салада жобалық тәсілді енгізудің негізгі артықшылықтары мен проблемалары айқындалды. Мемлекеттік басқару тиімділігін арттыру және Қазақстанның туристік индустриясын орнықты дамыту құралы ретінде жобалық басқаруды одан әрі жетілдіру қажеттілігі туралы қорытынды жасалды.

Түйінді сөздер: жобалық басқару, туризм, мемлекеттік басқару, туристік саясат, туристік индустрия, Ұлттық туристік өнім, Өңірлерді дамыту, басқарудың тиімділігі.

Кіріспе

Экономиканы дамытудың қазіргі жағдайында мемлекеттің әлеуметтік-экономикалық дамуының стратегиялық мақсаттарына қол жеткізуді қамтамасыз ететін басқарудың инновациялық әдістерін енгізу ерекше маңызға ие. Осындай құралдардың бірі-әлемнің көптеген елдерінің мемлекеттік басқару жүйесіне белсенді енгізіліп жатқан жобалық басқару.

Қазақстан Республикасы үшін туристік саланы дамыту экономиканы әртараптандырудың басым бағыттарының бірі болып айқындалды. Туризм халықты жұмыспен қамтуды ұлғайту, инвестициялар тарту, инфрақұрылымды дамыту және елдің халықаралық тартымдылығын арттыру үшін айтарлықтай әлеуетке ие. Осыған байланысты туризм саласындағы мемлекеттік бағдарламалар мен бастамаларды іске асыру кезінде жобалық тәсілді қолдану ерекше өзекті болып отыр [1].

Осы мақаланың мақсаты Қазақстан Республикасының Туризм саласындағы жобалық басқаруды қолдану ерекшеліктерін зерттеу және оны жетілдіру бағыттарын айқындау болып табылады.

Жобалық басқарудың теориялық негіздері

Жобалық басқару - бұл шектеулі ресурстармен белгіленген мерзімде нақты мақсаттарға жетуге бағытталған әдістер, құралдар мен процестер жүйесі. Халықаралық стандарттарға сәйкес, жоба бірегей өнімді, қызметті немесе нәтижені жасауға арналған уақытша кәсіпорын ретінде қарастырылады.

Жобалық басқарудың негізгі принциптері:

- нақты нәтижеге қол жеткізуге бағдарлану;
- жобаны іске асыру мерзімдерінің шектелуі;
- ресурстарды ұтымды пайдалану;
- тәуекелдерді басқару;
- ведомствоаралық өзара іс-қимыл;

- тұрақты мониторинг және орындалуын бақылау [2].

Дәстүрлі функционалды басқарудан айырмашылығы, жобалық тәсіл ресурстарды нақты стратегиялық мақсаттарға шоғырландыруға, шешім қабылдау процестерінің ашықтығын қамтамасыз етуге және жобаға қатысушылардың түпкілікті нәтижелер үшін жауапкершілігін арттыруға мүмкіндік береді.

Әлемдік тәжірибеде жобалық басқару инфрақұрылымдық, инвестициялық, Әлеуметтік және туристік жобаларды іске асыруда кеңінен қолданылады. Оны пайдалану мемлекеттік басқарудың тиімділігін арттыруға ықпал етеді және өлшенетін нәтижелерге қол жеткізуді қамтамасыз етеді.

Қазақстанның мемлекеттік секторында жобалық басқаруды дамыту

Соңғы жылдары Қазақстанда мемлекеттік органдардың қызметіне жобалық басқаруды енгізу бойынша жүйелі жұмыс жүргізілуде. Бұл процеске әкімшілік реформалар мен мемлекеттік басқаруды жаңғырту шеңберінде елеулі серпін берілді.

Қазіргі уақытта жобалық басқару ұлттық жобаларды, мемлекеттік бағдарламаларды және Өңірлік даму жоспарларын қоса алғанда, елдің стратегиялық құжаттарын іске асырудың негізгі құралдарының бірі ретінде қарастырылуда [3].

Мемлекеттік секторда жобалық басқаруды енгізудің негізгі мақсаттары:

- бюджет қаражатын пайдалану тиімділігін арттыру;
- дамудың стратегиялық көрсеткіштеріне қол жеткізу;
- ведомствоаралық үйлестіруді күшейту;
- басқару процестерінің ашықтығын қамтамасыз ету;
- мемлекеттік бастамаларды іске асыру мерзімдерін қысқарту [4].

Жобалық тәсіл туризм саласында ерекше маңызға ие, мұнда әртүрлі мемлекеттік органдардың, бизнес пен қоғамдық ұйымдардың қызметін үйлестіру қажет.

Қазақстан Республикасының Туризм саласындағы жобалық басқарудың ерекшеліктері

Туризм-көлік, қонақ үй шаруашылығы, қоғамдық тамақтану, мәдениет, спорт, экология және басқа да қызмет салаларын біріктіретін күрделі салааралық жүйе. Сондықтан туристік саясатты жүзеге асыру заманауи басқару технологияларын қолдануды талап етеді [5].

Қазақстанда туризмді дамыту бәсекеге қабілетті туристік өнімді қалыптастыруды және туризмнің ұлттық экономикаға үлесін арттыруды көздейтін Қазақстан Республикасының туристік саласын дамытудың 2023-2029 жылдарға арналған тұжырымдамасына сәйкес жүзеге асырылады [6].

Туристік саладағы жобалық басқару мынадай міндеттерді шешуге бағытталған:

- туристік инфрақұрылымды дамыту;
- жаңа туристік маршруттар мен дестинациялар құру;
- инвестицияларды тарту;
- туристік қызметтердің сапасын арттыру;
- халықаралық нарықта ұлттық туристік өнімді жылжыту;
- туристік саланы цифрландыру.

Туристік жобалардың маңызды ерекшелігі олардың кешенді сипаты болып табылады. Тіпті бір туристік нысанды іске асыру мемлекеттік органдардың, инвесторлардың, жергілікті атқарушы органдардың, туристік ұйымдар мен халықтың қатысуын талап етеді.

Жобалық тәсіл барлық мүдделі тараптардың күш-жігерін біріктіруге және белгіленген мерзімде жоспарланған нәтижелерге қол жеткізуді қамтамасыз етуге мүмкіндік береді [7].

Өңірлік деңгейде туристік жобаларды іске асыру

Туристік жобалардың едәуір бөлігі өңірлік деңгейде іске асырылуда. Туристерді тарту үшін әлеуеті жоғары туристік кластерлерді дамытуға ерекше назар аударылады.

Қазақстанның перспективалы туристік аумақтарының қатарына мыналар жатады:

- Щортанды-Бурабай курорттық аймағы;
- Алматы тау кластері;
- Маңғыстау туристік дестинациясы;
- Балқаш курорттық аймағы;
- Түркістан туристік орталығы;
- Қарқаралы туристік кластері.

Жобалық басқару шеңберінде аумақтарды дамытудың жол карталарын әзірлеу жүзеге асырылады, тиімділіктің негізгі көрсеткіштері, қаржыландыру көздері және іс-шараларды іске асыру мерзімдері айқындалады.

Қарағанды облысының туристік әлеуетін дамыту ерекше маңызға ие. Өңірде Қарқаралы ұлттық паркі, Балқаш көлі, индустриялық мұра объектілері және этномәдени кешендерді қоса алғанда, елеулі табиғи, мәдени және тарихи ресурстар бар.

Жобалық тәсілді қолдану облыстың туристік инфрақұрылымын кешенді дамытуды қамтамасыз етуге, өңірдің инвестициялық тартымдылығын арттыруға және туристік ағымды арттыруға мүмкіндік береді [8].

Туризмде жобалық басқаруды қолданудың артықшылықтары

Туристік салада жобалық басқаруды пайдалану бірқатар маңызды артықшылықтарды қамтамасыз етеді.

Біріншіден, жобалық тәсіл ресурстарды тиімді бөлуге ықпал етеді. Әрбір жобаның нақты белгіленген бюджеті, іске асыру мерзімі және күтілетін нәтижелері бар.

Екіншіден, басқару процестерінің ашықтығы артады. Мониторинг жүйесі жоспарланған көрсеткіштерден ауытқуларды уақтылы анықтауға және түзету шараларын қабылдауға мүмкіндік береді.

Үшіншіден, мемлекеттік органдар мен жеке сектор арасындағы үйлестіру жақсаруда. Бұл әсіресе бизнестің белсенді қатысуынсыз дамуы мүмкін емес туристік сала үшін өте маңызды.

Төртіншіден, тиімділіктің сандық және сапалық көрсеткіштерінде көрсетілген нақты нәтижелерге қол жеткізуге бағдарлау қамтамасыз етіледі.

Сонымен қатар, жобалық басқару жоспарлау мен бақылаудың заманауи әдістерін қолдану арқылы ірі инфрақұрылымдық жобаларды іске асыру тәуекелдерін азайтуға ықпал етеді [9].

Туристік салада жобалық басқаруды енгізу мәселелері

Айқын артықшылықтарға қарамастан, туризм саласында жобалық басқаруды енгізу бірқатар проблемалармен қатар жүреді.

Негізгілерінің бірі мемлекеттік қызметшілер мен туристік сала мамандарының жобалық менеджмент саласындағы құзыреттерінің жеткіліксіз деңгейі болып табылады.

Туристік жобалардың әр түрлі қатысушылары арасындағы үйлестіру жеткіліксіз, бұл функциялардың қайталануына және іс-шараларды іске асыру мерзімдерінің ұлғаюына әкеледі.

Қосымша қиындықтар қаржы ресурстарының шектеулілігімен, жекелеген өңірлерде туристік инфрақұрылымды дамытудың жеткіліксіз деңгейімен және саланың сыртқы факторларға жоғары тәуелділігімен байланысты.

Басқа мәселелердің ішінде мыналарды атап өтуге болады:

- басқару процестерін цифрландырудың жеткіліксіздігі;
- туристік жобалардың тиімділігін бағалаудың бірыңғай тәсілдерінің болмауы;
- басқарушылық шешімдер қабылдау үшін статистикалық деректердің шектелуі;
- жобаларды іске асыруға жергілікті қоғамдастықтарды тартудың жеткіліксіз деңгейі.

Аталған проблемаларды шешу үшін мемлекеттік сектордағы жобалық басқаруды одан әрі институттандыру және мамандардың біліктілігін арттыру қажет [10].

Қазақстан туризміндегі жобалық басқаруды дамыту перспективалары

Туристік салада жобалық басқаруды дамыту перспективалары мемлекеттік басқару жүйесін одан әрі жетілдірумен және цифрлық технологияларды енгізумен байланысты.

Басым бағыттар:

- туристік салада жобалық кеңселер құру;
- жобалар мониторингінің заманауи цифрлық платформаларын енгізу;
- мемлекеттік-жекешелік әріптестік тетіктерін дамыту;
- мамандардың кәсіби құзыреттілігін арттыру;
- жобалардың тиімділігін бағалау жүйесін жетілдіру;
- туристік жобаларды басқару саласындағы халықаралық ынтымақтастықты кеңейту.

Туристік ағындарды болжау және қабылданған шешімдердің тиімділігін бағалау үшін үлкен деректер, жасанды интеллект және цифрлық аналитика технологияларын пайдалану ерекше рөл атқарады.

Аталған шараларды кешенді іске асыру Қазақстанның туристік саласының бәсекеге қабілеттілігін арттыруға және елді дамытудың стратегиялық мақсаттарына қол жеткізуді қамтамасыз етуге мүмкіндік береді.

Қорытынды

Жобалық басқару туризм саласындағы мемлекеттік саясатты іске асырудың тиімді құралы болып табылады. Оны қолдану ресурстарды пайдаланудың тиімділігін арттыруды, жобаларға қатысушылар арасындағы үйлестіруді жақсартуды және туристік саланы дамытудың стратегиялық мақсаттарына қол жеткізуді қамтамасыз етеді.

Қазақстан Республикасы үшін жобалық тәсіл ішкі және келу туризмін дамыту жөніндегі ауқымды міндеттерді іске асыру жағдайында ерекше маңызға ие болады. Жобалық басқарудың заманауи әдістерін енгізу бәсекеге қабілетті туристік өнімді қалыптастыруға, өңірлерді дамытуға және туризмнің ұлттық экономикаға қосқан үлесін арттыруға ықпал етеді.

Жобалық басқару жүйесін одан әрі жетілдіру туризм саласындағы мемлекеттік басқаруды жаңғыртудың және саланың тұрақты дамуын қамтамасыз етудің негізгі бағыттарының бірі болуға тиіс.

Әдебиеттер тізімі

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Tikinti müəssisələrində ümumi istehsal xərclərinin uçotu və bölüşdürülməsi problemləri

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Abstract

The construction sector occupies a strategically important place in the economy of the Republic of Azerbaijan, accounting for 6.5 percent of the country's gross domestic product in 2025. Despite this significance, construction enterprises continue to face serious methodological challenges in the area of overhead cost accounting and allocation. The incorrect selection of allocation methods leads to systematic distortions in project cost calculations, pricing errors, and unreliable financial reporting.

This article investigates the accounting and allocation of overhead costs among construction projects, with a particular focus on three widely applied methods: the direct labor cost base method, the machine-hour base method, and the Activity-Based Costing (ABC) method. The study provides a comparative theoretical analysis of these methods, examining their respective advantages, limitations, and suitability for the specific characteristics of the construction industry, including long production cycles, simultaneous execution of multiple projects, high capital intensity, and seasonal fluctuations. The research demonstrates that the direct labor cost base method, which remains the most prevalent approach among Azerbaijani construction enterprises, is methodologically inadequate for capital-intensive projects and produces significant distortions in overhead allocation. The machine-hour base method offers a more appropriate alternative for technically complex projects, while the ABC method provides the highest degree of accuracy by applying separate allocation bases for each overhead cost category. The findings confirm the research hypothesis that the choice of allocation method materially affects project cost calculations. Practical recommendations are put forward for improving overhead cost accounting in Azerbaijani construction enterprises, including the phased introduction of the ABC method, the expansion of analytical accounting accounts, and the modernization of the regulatory framework in line with the requirements of IFRS 15.

Keywords: overhead costs, cost allocation, cost of production, ABC method, accounting.

Xülasə

Azərbaycan Respublikasının iqtisadiyyatında strateji əhəmiyyət daşıyan tikinti sektoru 2025-ci ildə ölkənin ümumi daxili məhsulunun 6,5 faizini təşkil etmişdir. Belə mühüm bir sənaye sahəsində fəaliyyət göstərən tikinti müəssisələri ümumi istehsal xərclərinin uçotu və bölüşdürülməsi sahəsində ciddi metodoloji problemlərlə üzləşməkdədir. Bölüşdürmə metodunun düzgün seçilməməsi layihə maya dəyərinin sistemli şəkildə təhrif edilməsinə, qiymət müəyyənləşdirilməsində xətalara və qeyri-dəqiq maliyyə hesabatlarının formalaşmasına gətirib çıxarır. Məqalədə tikinti layihələri arasında ümumi istehsal xərclərinin uçotu və bölüşdürülməsi tədqiq edilir; tətbiq olunan üç əsas metod olan birbaşa əmək haqqı bazası, maşın-saat bazası və

fəaliyyətə əsaslanan xərc (ABC) metodu müqayisəli şəkildə araşdırılır. Tədqiqat bu metodların hər birinin üstünlüklərini, məhdudiyyətlərini və tikinti sənayesinin özünəməxsus xüsusiyyətləri olan uzun istehsal dövrü, eyni vaxtda bir neçə layihənin icrası, yüksək texnika intensivliyi və mövsümi dəyişkənlik kontekstində tətbiq uyğunluğunu əhatəli şəkildə təhlil edir. Tədqiqat nəticəsində müəyyən edilmişdir ki, Azərbaycan tikinti müəssisələrinin praktikasında ən geniş yayılmış yanaşma olan birbaşa əmək haqqı bazasında bölüşdürmə metodu texnika intensiv layihələr üçün metodoloji cəhətdən qeyri-adekvat olub, ümumi istehsal xərclərinin bölüşdürülməsində əhəmiyyətli təhriflərə səbəb olur. Maşın-saat bazası metodu texniki cəhətdən mürəkkəb layihələr üçün daha uyğun alternativ təqdim edir. ABC metodu isə hər ümumi istehsal xərci kateqoriyası üçün ayrıca bölüşdürmə bazası tətbiq etməklə ən yüksək dəqiqlik dərəcəsini təmin edir. Əldə edilmiş nəticələr tədqiqatın əsas hipotezini bölüşdürmə metodunun seçiminin layihə maya dəyərində əhəmiyyətli dərəcədə təsir etdiyini təsdiqləyir. Azərbaycan tikinti müəssisələrində ümumi istehsal xərclərinin uçotunun təkmilləşdirilməsi məqsədilə ABC metodunun mərhələli tətbiqi, analitik uçot hesablarının genişləndirilməsi və normativ bazanın MHBS 15-in tələblərinə uyğun müasirləşdirilməsi istiqamətlərində praktik tövsiyələr irəli sürülmüşdür.

Açar sözlər: ümumi istehsal xərcləri, xərclərin bölüşdürülməsi, maya dəyəri, ABC metodu, mühasibat uçotu.

Giriş

Mövzunun aktuallığı. Tikinti sektoru Azərbaycan Respublikasının iqtisadiyyatında mühüm yer tutan sahələrdən biri olmaqla, 2025-cü ildə ölkənin ümumi daxili məhsulunun 6,5 faizini təşkil etmişdir. Sektorun qeyri-neft iqtisadiyyatının inkişafındakı strategji rolu, eyni zamanda əhalinin məşğulluğuna, infrastrukturun genişlənməsinə və regional inkişafa verdiyi töhfə onu daim diqqət mərkəzində saxlayır. (AR Dövlət Statistika Komitəsi. 2025-cü ildə Ümumi Daxili Məhsul istehsalı) Belə bir mühüm sənaye sahəsində müəssisələrin rəqabət qabiliyyəti, maliyyə dayanıqlığı və layihə idarəetməsinin səmərəliliyi bilavasitə xərclərin düzgün uçotu ilə bağlıdır. Tikinti müəssisələrinin fəaliyyəti özünəməxsus xüsusiyyətlərə (uzun istehsal dövrünə, eyni vaxtda bir neçə layihənin icrasına, mövsümi xərc dəyişkənliyinə və böyük həcmli avadanlıq-texnika xərclərinə) malikdir. Bu xüsusiyyətlər ümumi istehsal xərclərinin (bundan sonra, ÜİX) müxtəlif layihələr arasında bölüşdürülməsini xüsusilə mürəkkəb bir məsələyə çevirir.

ÜİX- amortizasiya, texnika saxlama, köməkçi işçi əmək haqqı, icarə, enerji və sair xərcləri əhatə edən tikinti maya dəyərində əhəmiyyətli bir hissəsini təşkil edir. Lakin bu xərclərin layihələrə düzgün nisbətdə aid edilməməsi ciddi nəticələrə gətirir: bəzi layihələrin maya dəyəri süni olaraq artır, digərlərininki isə azalır; bu da qiymət müəyyənləşdirilməsində və mənfəət hesablanmasında metodoloji xətalara yol açır. Azərbaycan tikinti müəssisələrinin praktikasında ÜİX əksər hallarda yalnız birbaşa əmək haqqı bazasında bölüşdürülür. Halbuki müasir idarəetmə uçotu metodları xüsusilə fəaliyyətə əsaslanan xərc (Activity-Based Costing- ABC) metodu daha ədalətli bölüşdürmə imkanı təqdim edir. Bu metodların tədqiq edilməsi və Azərbaycan şəraitinə uyğunlaşdırılması həm nəzəri, həm də praktik baxımdan aktualdır.

Tədqiqatın əsas məqsədi

Tədqiqatın əsas məqsədi tikinti müəssisələrində ümumi istehsal xərclərinin uçotu və layihələr arasında bölüşdürülməsi metodlarını müqayisəli şəkildə təhlil etmək, mövcud metodoloji problemləri müəyyənləşdirmək və Azərbaycan tikinti müəssisələri üçün xərclərin daha düzgün və ədalətli bölüşdürülməsinə dair praktik tövsiyələr hazırlamaqdır. Məqsədə çatmaq üçün aşağıdakı vəzifələr müəyyən edilmişdir:

- 1) ÜİX-nin iqtisadi mahiyyətini və tikinti sahəsinə xas xüsusiyyətlərini araşdırmaq;
- 2) mövcud bölüşdürmə metodlarını; əmək haqqı bazası, maşın-saat bazası və ABC metodu müqayisəli təhlil etmək;

3) Azərbaycan tikinti müəssisələrinin praktikasında mövcud vəziyyəti qiymətləndirmək və təkmilləşdirmə istiqamətlərini müəyyən etmək.

İrəli sürülən hipotez

Tədqiqatın əsas hipotezi aşağıdakı kimi formalaşdırılır:

Tikinti müəssisələrində ümumi istehsal xərclərinin bölüşdürülməsində tətbiq edilən metodun seçimi layihə maya dəyərini əhəmiyyətli dərəcədə təhrif edir; fəaliyyətə əsaslanan xərc (ABC) metodu ənənəvi bölüşdürmə metodları ilə müqayisədə daha ədalətli və dəqiq nəticə verir. Bu hipotezdən çıxış edərək irəli sürülən əlavə fərziyyələr bunlardır:

- 1) Eyni ÜİX həcmi fərqli bölüşdürmə bazaları tətbiq edildikdə müxtəlif layihələr üzrə əhəmiyyətli dərəcədə fərqli maya dəyəri göstəriciləri formalaşdırır;
- 2) Azərbaycan tikinti müəssisələrinin böyük əksəriyyəti hələ də sadə, lakin metodoloji cəhətdən qüsurlu bölüşdürmə bazalarından istifadə edir;
- 3) ABC metodunun tətbiqi xərclərin şəffaflığını artırır və müəssisə rəhbərliyinin qərar qəbulunu daha etibarlı məlumat bazasına söykəndirir.

Ədəbiyyat icmalı

Ümumi istehsal xərclərinin uçotu və layihələr arasında bölüşdürülməsi məsələsi mühasibat uçotu və idarəetmə uçotu elminin əsas tədqiqat istiqamətlərindən birini təşkil edir. Bu sahədə aparılmış tədqiqatları üç qrupa bölmək mümkündür: beynəlxalq nəzəri tədqiqatlar, tikinti sahəsinə xas metodoloji işlər və Azərbaycan kontekstindəki tədqiqatlar. Beynəlxalq nəzəri tədqiqatlar: Xərclərin təsnifatı, uçotu və bölüşdürülməsi metodlarının nəzəri əsasları beynəlxalq idarəetmə uçotu ədəbiyyatında geniş işıqlandırılmışdır. Amerikalı alimlər Çarlz Hornqren, Srikant Datar və Madhav Rajan öz fundamental dərslərində birbaşa və dolayısı xərclərin fərqləndirilməsini müfəssəl şəkildə araşdırmış, ənənəvi həcm bazalı bölüşdürmə metodlarının müasir istehsal şəraitində yaratdığı metodoloji məhdudiyətlərə diqqət çəkmişlər. Müəlliflər fəaliyyətə əsaslanan xərc metodunu(ABC metodu) bu məhdudiyətlərə alternativ kimi təqdim etmiş və onun daha dəqiq xərc məlumatı təmin etdiyini sübut etmişlər [Hornqren C.T., Datar S.M., Rajan M.V. *Cost Accounting: A Managerial Emphasis*. 16th ed. Pearson Education, 2018].

Britaniyalı alim Kolin Druri idarəetmə uçotuna həsr olunmuş əsərində ABC metodunun tətbiqinin xüsusilə çoxsaylı layihə aparan müəssisələrdə o cümlədən tikinti şirkətlərində əhəmiyyətli üstünlüklər verdiyini göstərmişdir. Druriyə görə, ənənəvi əmək haqqı bazasında bölüşdürmə yalnız əmək intensivliyi yüksək olan istehsaatlarda ədalətli nəticə verir; texnika və avadanlıqdan geniş istifadə edilən tikinti sahəsində isə bu metod xərc məlumatlarını ciddi şəkildə təhrif edə bilər [Drury C. *Management and Cost Accounting*. 10th ed. Cengage Learning, 2018]. Tikinti sahəsinə xas metodoloji tədqiqatlar: Rus alimi Larisa Gerasimova tikinti müəssisələrinin mühasibat uçotuna həsr olunmuş dərslərində ÜİX-nin layihələr arasında bölüşdürülməsinin tikintiyə xas uzun istehsal dövrü, mövsümlilik amili və eyni vaxtda bir neçə obyektin inşası kimi xüsusiyyətlər səbəbindən digər sənaye sahələrinə nisbətən daha mürəkkəb bir məsələ olduğunu əsaslandırmışdır [Герасимова Л.Н. *Бухгалтерский учёт в строительстве*. Москва: КНОРУС, 2023].

Rus alimləri Mariya Vaxruşina və Vaqif Kərimov idarəetmə uçotu dərslərində ümumi istehsal xərclərinin sabit və dəyişən hissələrə ayrılmasının bölüşdürmə dəqiqliyini əhəmiyyətli dərəcədə artırdığını göstərmişlər. Müəlliflərə görə, xərclərin bu şəkildə təsnif edilməsi müəssisə rəhbərliyinə həm qısamüddətli, həm də uzunmüddətli qərarların qəbulunda daha etibarlı informasiya bazası təqdim edir [Вахрушина М.А. *Бухгалтерский управленческий учёт*. Москва: Национальное образование, 2013; Керимов В.Э. *Бухгалтерский управленческий учёт*. Москва: Дашков и К, 2014].

Beynəlxalq standartlar kontekstində tədqiqatlar: MHBS 15 olan "Müştərilərlə müqavilələrdən gəlirlər" standartının tikinti sektoruna təsiri beynəlxalq tədqiqatçıların da diqqətini çəkmişdir. PwC-nin analitik hesabatında isə MHBS 15-ə keçidin tikinti müəssisələrinin xərc uçotu sistemlərinə ciddi metodoloji tələblər qoyduğu, xüsusilə ÜİX-nin layihələrə aid edilməsi mexanizminin yenidən qurulması zərurəti vurğulanmışdır [PricewaterhouseCoopers. *IFRS 15: Impact on Engineering and Construction Sector*. PwC Technical Report, 2014].

Azərbaycan kontekstindəki tədqiqatlar: Tikinti sektoru Azərbaycan Respublikasının iqtisadiyyatında mühüm yer tutan sahələrdən biri olmaqla, 2024-cü ildə ölkənin ümumi daxili məhsulunun 6,7 faizini təşkil etmişdir. Əliyev və Məmmədovun (2022) apardığı empirik tədqiqat sübut etmişdir ki, tikinti sektoru ilə iqtisadi artım arasında iki istiqamətli qarşılıqlı əlaqə mövcuddur — tikintinin inkişafı iqtisadi artımı stimullaşdırır, iqtisadi artım isə öz növbəsində tikinti sektoruna investisiya axınını gücləndirir [Aliyev, V., & Mammadov, T. (2022). The mutual impact of economic growth and the construction sector in Azerbaijan: An empirical approach. *Azerbaijan Economic Journal*, 30(2), 45–59]. Bu qarşılıqlı əlaqə tikinti sektorunun Azərbaycan iqtisadiyyatının inkişafında struktural rol oynadığını göstərir və həmin sektorda xərclərin düzgün uçotunun iqtisadi əhəmiyyətini daha da artırır. Aparılmış ədəbiyyat icmalı göstərir ki, beynəlxalq tədqiqatlar ümumi istehsal xərclərinin bölüşdürülməsi metodologiyasını nəzəri cəhətdən yetərli dərəcədə əsaslandırmışdır. Lakin Azərbaycan tikinti müəssisələrinin real praktikasına söykənən, fərqli bölüşdürmə metodlarının maya dəyərində təsirini kəmiyyət baxımından müqayisə edən tədqiqatlar ədəbiyyatda demək olar ki, yer almamışdır. Hazırkı tədqiqat məhz bu elmi boşluğu doldurmaq məqsədi güdür.

Metodologiya

Tədqiqatda məqsədə çatmaq üçün bir-birini tamamlayan bir neçə elmi metod və yanaşmadan istifadə edilmişdir. Tədqiqat əsasən müqayisəli-analitik xarakter daşıyır. Mövcud bölüşdürmə metodlarının üstünlük və çatışmazlıqları müqayisəli təhlil vasitəsilə araşdırılmış, şərti rəqəmsal nümunə üzərindən isə hər metodun maya dəyərində təsiri kəmiyyət baxımından modelləşdirilmişdir. İstifadə edilən metodlar:

Ədəbiyyatın sisteməlik təhlili - ümumi istehsal xərclərinin uçotu və bölüşdürülməsinə dair beynəlxalq və yerli elmi mənbələr, o cümlədən dərsliklər, elmi məqalələr, dissertasiyalar və normativ sənədlər sistemli şəkildə öyrənilmişdir.

Müqayisəli təhlil - üç əsas bölüşdürmə metodu olan birbaşa əmək haqqı bazası, maşın-saat bazası və fəaliyyətə əsaslanan xərc (ABC) metodu müəyyən meyarlar üzrə müqayisəli cədvəl şəklində təhlil edilmişdir.

Rəqəmsal modelləşdirmə - eyni tikinti müəssisəsinin üç paralel layihəsinə ümumi istehsal xərclərinin fərqli bazalar üzrə bölüşdürülməsi şərti rəqəmsal nümunə vasitəsilə modelləşdirilmiş, hər metodun verdiyi maya dəyəri nəticələri müqayisə edilmişdir. Şərti rəqəmlər real tikinti müəssisələrinin orta göstəricilərinə əsaslanır.

Abstraksiya və ümumiləşdirmə - tədqiqat nəticəsində əldə edilmiş tapıntılar ümumiləşdirilmiş, Azərbaycan tikinti müəssisələri üçün praktik tövsiyələr formalaşdırılmışdır.

Tədqiqatın nəzəri bazasını Beynəlxalq Maliyyə Hesabatları Standartları xüsusilə MHBS 15 və MUBS 11, idarəetmə uçotu üzrə fundamental dərsliklər, elmi məqalələr və Azərbaycan Respublikasının normativ-hüquqi aktları təşkil edir. Rəqəmsal nümunənin parametrləri isə tikinti sektorunun orta xərc strukturuna uyğun olaraq müəllif tərəfindən müəyyən edilmişdir. Qeyd etmək lazımdır ki, tədqiqatda istifadə edilən rəqəmsal nümunə şərti xarakter daşıyır və konkret bir müəssisənin məlumatlarına əsaslanmır.

Əsas tədqiqat işi

1. Ümumi istehsal xərclərinin mahiyyəti və tikinti sahəsinə xas xüsusiyyətləri

Mühasibat uçotu nəzəriyyəsində xərclər iki əsas qrupa bölünür: birbaşa xərclər və dolayısı xərclər. Birbaşa xərclər konkret bir məhsula, layihəyə və ya xidmətə birbaşa aid edilə bilən xərclərdir. Tikinti sahəsində buna misal olaraq beton, metal konstruksiya, kərpic kimi əsas materialları və fəhlələrin birbaşa əmək haqqını göstərmək olar. Dolayısı xərclər isə bir neçə layihəyə eyni vaxtda aid olan, lakin hər birinə ayrı-ayrılıqda birbaşa nisbət verilməsi mümkün olmayan xərclərdir. Məhz bu ikinci qrup olan ümumi istehsal xərcləri tədqiqatımızın əsas predmetini təşkil edir. Ümumi istehsal xərclərinin (ÜİX) tərkibinə adətən aşağıdakılar daxildir:

- 1) tikinti maşın və mexanizmlərinin amortizasiyası;
- 2) avadanlıq və texnikanın saxlanması, təmiri xərcləri;
- 3) istehsalat binaları və anbarların icarə xərcləri;
- 4) enerji, yanacaq və kommunal xərclər;
- 5) köməkçi işçilərin
- 6) ustalar, nəzarətçilər, sürücülər
- 7) əmək haqqı;
- 8) istehsalat təhlükəsizliyi və əmək mühafizəsi xərcləri və ümumi istehsalat xarakterli digər xərclər

Tikinti sektoru ÜİX-nin idarə edilməsi baxımından digər sənaye sahələrindən bir sıra əsaslı xüsusiyyətlərinə görə fərqlənir. İstehsal müəssisəsindən fərqli olaraq tikinti şirkəti eyni vaxtda müxtəlif yerlərdə, müxtəlif həcmli və müxtəlif müddətli bir neçə layihə aparır. Bu xüsusiyyət ÜİX-nin hansı layihəyə nə qədər aid ediləcəyini müəyyən etməyi xeyli çətinləşdirir. Tikinti sahəsinin ÜİX uçotuna təsir edən başlıca xüsusiyyətlərini aşağıdakı kimi sistemləşdirmək olar:

Uzun istehsal dövrü- tikinti layihələri aylarla, bəzən illərlə davam edir. Bu, ÜİX-nin hansı hesabat dövrünə aid ediləcəyi məsələsini mürəkkəbləşdirir; mövsümi xərclər məsələn, qışda isitmə xərcləri müxtəlif aylara qeyri-bərabər şəkildə düşür.

Eyni vaxtda bir neçə layihənin aparılması- bir tikinti şirkəti eyni dövrdə, məsələn, həm yaşayış kompleksi, həm körpü, həm də sənaye obyektini tikə bilər. Eyni texnika, eyni ustalar və eyni anbar bütün bu layihələrə xidmət edir. ÜİX-nin bu layihələr arasında ədalətli bölüşdürülməsi ciddi metodoloji məsələyə çevrilir.

Yüksək avadanlıq intensivliyi- müasir tikintidə kranlar, ekskavatorlar, beton qarışdırıcılar və digər ağır texnikadan geniş istifadə olunur. Bu texnikanın amortizasiyası və saxlanma xərclərinin ümumi maya dəyərindəki payı əhəmiyyətli dərəcədə yüksəkdir. Bu xüsusiyyət səbəbindən tikintidə ÜİX-nin düzgün bölüşdürülməsi digər sənaye sahələrinə nisbətən daha böyük əhəmiyyət kəsb edir.

Mövsümlilik- tikinti fəaliyyəti ilin fəsilindən asılı olaraq dəyişir. Yay aylarında tikinti həcmi artır, qış aylarında isə əhəmiyyətli dərəcədə azalır. Lakin texnikanın amortizasiyası, icarə və sair sabit xərclər bütün il boyu davam edir. Bu da ÜİX-nin aylıq bölüşdürülməsini qeyri-bərabər edir.

Podrat münasibətlərinin mürəkkəbliyi- tikinti layihələrinin bir hissəsi subpodratçılara verilir. Belə hallarda ÜİX-nin yalnız baş podratçının fəaliyyətinə aid olan hissəsinin düzgün müəyyənəndirilməsi əlavə çətinliklər yaradır.

Bütün bu xüsusiyyətlər birlikdə onu göstərir ki, tikinti sahəsində ÜİX-nin idarə edilməsi üçün universal bir metod mövcud deyil. Hər müəssisənin fəaliyyət xüsusiyyətlərinə, layihə portfelinə və texniki bazasına uyğun olaraq ən münasib bölüşdürmə metodunun seçilməsi zəruridir. Növbəti bölmədə mövcud metodlar müqayisəli şəkildə araşdırılacaqdır.

2. Ümumi istehsal xərclərinin layihələr arasında bölüşdürülməsi metodları

Ümumi istehsal xərclərinin layihələr arasında bölüşdürülməsi üçün praktikada bir neçə metod tətbiq edilir. Hər metodun özünəməxsus üstünlükləri və çatışmazlıqları mövcuddur. Aşağıda üç əsas metod ardıcıl olaraq araşdırılır.

2.1. Birbaşa əmək haqqı bazasında bölüşdürmə metodu

Bu metod praktikada ən geniş yayılmış ənənəvi yanaşmadır. Metodun mahiyyəti bundan ibarətdir: hər layihəyə aid ediləcək ÜİX həcmi, həmin layihədə çəkilən birbaşa əmək haqqının

ümumi birbaşa əmək haqqına nisbəti əsasında hesablanır. Başqa sözlə, hansı layihədə daha çox fəhlə əməyi istifadə edilərsə, həmin layihəyə daha çox ÜİX aid edilir.

Metodun üstünlükləri: hesablanması sadədir, mühasibat uçotunda mövcud məlumatlardan birbaşa istifadə etməyə imkan verir, tətbiqi xüsusi texniki hazırlıq tələb etmir.

Metodun çatışmazlıqları: müasir tikintidə əmək intensivliyi azalmış, buna müqabil texnika intensivliyi artmışdır. Buna görə də texniki cəhətdən mürəkkəb layihələrdə məsələn, körpü və ya tunelin inşasında texnika xərcləri əmək xərclərindən qat-qat çox olur. Belə hallarda əmək haqqı bazasında bölüşdürmə ÜİX-ni düzgün əks etdirmir və maya dəyərini ciddi şəkildə təhrif edir.

2.2. Maşın-saat bazasında bölüşdürmə metodu

Bu metod texnika intensivliyi yüksək olan sənaye sahələri, o cümlədən tikinti üçün daha uyğun hesab edilir. Metodun əsasını hər layihədə istifadə edilən maşın və mexanizmlərin işlədildiyi saat sayı təşkil edir. Ümumi istehsal xərcləri layihələr arasında onların maşın-saat istifadəsinə mütənəsb olaraq bölüşdürülür.

Metodun üstünlükləri: texnika xərclərinin məsələn, amortizasiya, yanacaq, təmir əsaslı pay təşkil etdiyi tikinti sahəsində daha ədalətli bölüşdürmə nəticəsi verir. Layihənin texniki mürəkkəbliyi dərəcəsini maya dəyərində daha düzgün şəkildə əks etdirir.

Metodun çatışmazlıqları: hər layihə üzrə maşın-saat uçotunun aparılması əlavə administrativ iş tələb edir. Bundan əlavə, müxtəlif texnika növlərinin məsələn, kranın və ekskavatorun saat dəyərləri fərqlidir; bütün texnikanı eyni vahidlə ölçmək bu fərqi nəzərə almır.

2.3. Fəaliyyətə əsaslanan xərc metodu (ABC metodu)

ABC(Activity-Based Costing) metodu ənənəvi metodların məhdudiyətlərini aradan qaldırmaq məqsədilə işlənilib hazırlanmışdır. Metodun məntiqi budur: ÜİX-nin hər komponenti onu yaradan konkret fəaliyyət növü ilə əlaqələndirilir, sonra isə hər layihənin həmin fəaliyyətdən nə qədər istifadə etdiyi müəyyənləşdirilir. Məsələn, kran xərcləri kran-saat sayına, anbar xərcləri material hərəkətlərinin sayına, nəzarət xərcləri isə yoxlama ziyarətlərinin sayına görə bölüşdürülür.

Metodun üstünlükləri: hər xərc növü üçün ayrı-ayrı bölüşdürmə bazası tətbiq edilir. Bu isə ÜİX-nin layihələrə çox daha dəqiq aid edilməsini təmin edir. ABC metodu xüsusilə müxtəlif xarakterli layihələri eyni vaxtda aparən müəssisələrdə ənənəvi metodlara nisbətən əhəmiyyətli dərəcədə daha dəqiq nəticə verir.

Metodun çatışmazlıqları: tətbiqi mürəkkəbdir, ətraflı fəaliyyət təhlili və əlavə uçot sistemi tələb edir. Kiçik həcmli tikinti müəssisələri üçün bu metodun tətbiqi həmişə iqtisadi cəhətdən əlçatan deyil. ABC metodu dəqiqlik baxımından digər metodlardan üstündür, lakin tətbiqinin mürəkkəbliyi onun Azərbaycan tikinti müəssisələrində geniş tətbiqinə mane olur.

Nəticə və Təkliflər

Aparılmış tədqiqat göstərir ki, tikinti müəssisələrində ümumi istehsal xərclərinin uçotu və layihələr arasında bölüşdürülməsi məsələsi həm nəzəri, həm də praktik baxımdan ciddi əhəmiyyət daşıyır. Tədqiqat çərçivəsində əldə edilmiş əsas nəticələr aşağıdakı kimi ümumiləşdirilə bilər. Birincisi, ümumi istehsal xərclərinin mahiyyəti və tərkibi tikinti sahəsinin özünəməxsus xüsusiyyətləri uzun istehsal dövrü, eyni vaxtda bir neçə layihənin aparılması, yüksək texnika intensivliyi və mövsümlilik ilə sıx bağlıdır. Bu xüsusiyyətlər ÜİX-nin idarə edilməsini digər sənaye sahələrinə nisbətən əhəmiyyətli dərəcədə mürəkkəbləşdirir. İkincisi, mövcud bölüşdürmə metodlarının müqayisəli təhlili göstərir ki, ənənəvi birbaşa əmək haqqı bazasında bölüşdürmə metodu müasir tikintinin texnika intensiv xarakterinə uyğun gəlmir. Bu metodun tətbiqi texnika intensiv layihələrin maya dəyərini sistemli olaraq aşağı, əmək intensiv layihələrin maya dəyərini isə yuxarı göstərir. Nəticədə müəssisənin qiymət siyasəti, mənfəət hesablamaları və strateji qərarları qeyri-dəqiq məlumatlara əsaslanır. Üçüncüsü, maşın-saat bazasında bölüşdürmə metodu texnika intensiv tikinti müəssisələri üçün ənənəvi metoddan daha uyğundur. Lakin bu metod da ÜİX-nin bütün komponentlərini vahid bazada ölçdüyündən tam dəqiq nəticə verə bilmir. Dördüncüsü,

fəaliyyətə əsaslanan xərc metodu(ABC metodu) hər ÜİX növü üçün ayrıca bölüşdürmə bazası tətbiq etdiyi üçün ən dəqiq nəticəni təmin edir. Bu metodun tətbiqi xüsusilə müxtəlif xarakterli layihələri eyni vaxtda aparan orta və iri tikinti müəssisələri üçün tövsiyə edilə bilər. ABC metodunun tətbiqi qısamüddətli inzibati xərclərin artmasına baxmayaraq, uzunmüddətli perspektivdə müəssisəyə daha etibarlı xərc məlumatı təqdim etməklə strateji üstünlük yaradır.

Tədqiqat nəticəsində Azərbaycan tikinti müəssisələri üçün aşağıdakı praktik tövsiyələr irəli sürülür:

- 1) Müəssisələr tətbiq etdikləri bölüşdürmə metodunu layihə portfelinin xüsusiyyətlərinə uyğun olaraq müntəzəm surətdə yenidən qiymətləndirməlidirlər; texnika intensivliyi yüksək olan müəssisələr üçün əmək haqqı bazasından maşın-saat bazasına keçid minimum addım kimi tövsiyə edilir.
- 2) Orta və iri tikinti müəssisələri ABC metodunun tətbiqini ciddi şəkildə nəzərdən keçirməlidirlər; bu zaman mühasibat uçotu proqram təminatının imkanlarından məsələn, 1C və ya SAP modullarından istifadə inzibati yükü əhəmiyyətli dərəcədə azalda bilər.
- 3) ÜİX sabit və dəyişən komponentlərə ayrılmalıdır; bu bölgü həm daha dəqiq bölüşdürmə, həm də müəssisənin boşdayanma dövrlərindəki xərc idarəetməsi üçün vacibdir.
- 4) Azərbaycan Respublikasının müvafiq qurumları tikinti müəssisələri üçün ÜİX uçotuna dair metodiki tövsiyələr hazırlamalı və MHBS 15-in tələblərinə uyğun standartlaşdırılmış uçot qaydaları müəyyənləşdirməlidirlər.

Tədqiqat nəticəsində irəli sürülən strateji təkliflər:

Tikinti müəssisələrində ümumi istehsal xərclərinin uçotu və bölüşdürülməsi sisteminin təkmilləşdirilməsi məqsədilə aparılmış tədqiqat əsasında aşağıdakı strateji təkliflər irəli sürülür. Təkliflər üç səviyyədə; müəssisə, sahə və dövlət səviyyəsində qruplaşdırılmışdır.

1. Müəssisə səviyyəsində strateji təkliflər

Bölüşdürmə metodunun yenidən qiymətləndirilməsi. Hər tikinti müəssisəsi öz layihə portfelinin xüsusiyyətlərini texnika intensivliyi, əmək intensivliyi, layihələrin müddəti və mürəkkəbliyi dərəcəsi nəzərə alaraq tətbiq etdiyi ÜİX bölüşdürmə metodunu ən azı ildə bir dəfə yenidən qiymətləndirməlidir. Texnika intensivliyi üstünlük təşkil edən müəssisələr üçün birbaşa əmək haqqı bazasından maşın-saat bazasına keçid prioritet addım kimi müəyyənləşdirilməlidir.

ABC metodunun mərhələli tətbiqi. Orta və iri tikinti müəssisələri ABC metoduna keçidi birdəfəlik deyil, mərhələli şəkildə həyata keçirməlidirlər. Birinci mərhələdə ÜİX-nin yalnız ən böyük komponenti texnika amortizasiyası üçün ayrıca bölüşdürmə bazası tətbiq edilə bilər. Bu, mühasibat sisteminin yenidən qurulmasını asanlaşdırır və kadrların yeni metoda uyğunlaşmasına imkan yaradır.

Analitik uçot hesablalarının genişləndirilməsi. ÜİX sabit və dəyişən komponentlərə ayrılmalı, hər komponent üçün ayrı analitik subhesab açılmalıdır. Sabit xərclər olan amortizasiya, icarə istehsal həcmindən asılı olmayaraq davam etdiyindən onların layihələrə bölüşdürülməsi dəyişən xərclərdən fərqli metodla aparılmalıdır. Bu yanaşma həm daha dəqiq maya dəyəri hesablanmasına, həm də boşdayanma dövrlərinin maliyyə nəticələrinə düzgün əks etdirilməsinə kömək edir.

Rəqəmsal uçot sistemlərinin tətbiqi. ABC metodunun əl ilə aparılması inzibati yükü artırır. Bu problemi aradan qaldırmaq üçün müəssisələr ixtisaslaşmış proqram təminatından istifadə etməlidirlər. Bu sistemlər hər layihə üzrə xərcləri avtomatik izləyir, bölüşdürməni real vaxt rejimində həyata keçirir və müəssisə rəhbərliyinə operativ hesabatlar təqdim edir.

Daxili audit mexanizminin gücləndirilməsi. ÜİX bölüşdürməsinin düzgünlüyü müntəzəm daxili audit vasitəsilə yoxlanılmalıdır. Xüsusilə uzunmüddətli layihələrdə hər hesabat dövrünün sonunda faktiki ÜİX göstəriciləri planlaşdırılmış göstəricilərlə müqayisə edilməli, kənarlaşmalar təhlil edilməlidir.

2. Sahə səviyyəsində strateji təkliflər

Sənaye birliklərinin metodiki rolu. Azərbaycan tikinti müəssisələrinin peşəkar birlikləri o cümlədən müvafiq sənaye assosiasiyaları ÜİX uçotunun aparılmasına dair sənayə üzrə vahid metodiki bələdçi hazırlamalılardır. Bu bələdçi müxtəlif ölçülü müəssisələr üçün tövsiyə edilən bölüşdürmə metodlarını, nümunəvi hesab planını və praktik nümunələri əhatə etməlidir.

Kadr hazırlığının gücləndirilməsi. Azərbaycan tikinti müəssisələrinin mühasibləri və maliyyəçiləri arasında idarəetmə uçotu metodları, xüsusilə ABC metodu barədə bilik səviyyəsi aşağıdır. Peşəkar təlim proqramları və sertifikatlaşdırma kursları vasitəsilə bu boşluğun aradan qaldırılması sahə üzrə ümumi uçot keyfiyyətini yüksəldəcəkdir.

3. Dövlət səviyyəsində strateji təkliflər

Normativ bazanın müasirləşdirilməsi. Azərbaycan Respublikasının müvafiq icra hakimiyyəti orqanları tikinti müəssisələri üçün ÜİX uçotuna dair normativ metodiki göstərişlər hazırlamalı və dərc etməlidirlər. Mövcud normativ baza bu sahədə kifayət qədər təfərrüatlı tənzimləmə təmin etmir.

MHBS-ə uyğunlaşdırmanın sürətləndirilməsi. Dövlət tikinti müəssisələrinin MHBS 15-in tələblərinə tam uyğunlaşdırılması prosesini dəstəkləməli, bu istiqamətdə metodiki yardım və keçid dövrü güzəştləri təqdim etməlidir. MHBS 15-in tam tətbiqi ÜİX-nin layihələrə aid edilməsi mexanizminin beynəlxalq standartlara cavab verən şəkildə yenidən qurulmasını zəruri edir.

Statistik uçotun təkmilləşdirilməsi. Dövlət Statistika Komitəsi tikinti müəssisələrinin xərc strukturuna dair daha ətraflı statistik məlumatlar toplamalı və dərc etməlidir. Bu məlumatlar həm tədqiqatçılar üçün etibarlı empirik baza, həm də müəssisələr üçün müqayisə meyarı rolunu oynayacaqdır.

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GLOBAL CARBON MARKETS AND CLIMATE FINANCE: CHALLENGES AND OPPORTUNITIES FOR DEVELOPING ECONOMIES

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Abstract: This article examines how global carbon markets operate, the failure of which when measured against its possible potential, and its effects on the developing countries struggling to finance their low-carbon development through the means of carbon trading mechanisms. Using the information from the World Bank, the International Monetary Fund, Climate Policy Initiative, and UNFCCC, this essay discusses carbon market compliance and voluntarism, the movement of climate finance, and obstacles that hinder the utilization by poor countries of both approaches. Pricing for carbon currently affects 29% of all global emissions, raising more than USD 107 billion annually but still lagging behind Paris Agreement targets. Annual climate finance reached over USD 2 trillion by 2024 but is highly unevenly distributed across the globe, accounting for less than 3% of GDP in sub-Saharan Africa. The core of this problem is that the shortcomings in the carbon market and in access to climate finance are interconnected: the latter depends on fixing the former.

Keywords: carbon markets, climate finance, carbon pricing, developing economies, green transition, UNFCCC, emissions trading, carbon tax, energy transition.

1. Introduction

Carbon pricing and climate finance have become two of the most contested issues in international economic policy. The Paris Agreement (UNFCCC, 2015) committed its signatories to holding warming well below 2°C, which means, in practical terms, that most economies need to stop making fossil fuels cheap to burn. Market-based instruments that attach a price to emissions are the standard economic prescription, but turning that prescription into functioning policy has proven far harder than the theory suggests, and the difficulties are not evenly distributed across countries.

Carbon pricing now covers approximately 29% of global greenhouse gas emissions, with annual revenues exceeding USD 107 billion in 2025 (World Bank, 2026). This figure represents genuine progress; however, the average price worldwide remains well below the USD 50 to 100 per tonne range that scientists consider the minimum needed to meet Paris targets. Most emissions remain underpriced, and the majority of revenue comes from a single scheme.

The underlying economics are not complicated. Fossil fuel users do not internalize the cost of the emissions they produce, so they emit more than they would if the cost were incorporated into their decision-making. A carbon tax or a tradable permit scheme changes that by attaching a price to emissions. Coase (1960) and Weitzman (1974) formalized why this works in theory, and a substantial body of subsequent literature has examined the practical design trade-offs between the two instruments (Goulder & Schein, 2013; Stavins, 2003). Stern (2007) provided the most influential welfare-economic case for treating climate change as a market failure requiring urgent corrective intervention. The practical record is considerably more uneven, and for developing

countries especially, participation in carbon markets has been more limited than the economics would predict (Hepburn et al., 2020).

Those countries face the sharpest version of the problem. They bear the worst physical consequences of a warming climate, have the least fiscal room to respond, and struggle to access the international capital needed to invest in cleaner energy. The commitment made by rich nations at Copenhagen in 2009 to mobilize USD 100 billion per year in climate finance for developing countries went unmet for over a decade, and what did arrive was mostly loans rather than grants (OECD, 2023). The gap between promise and delivery has eroded trust in the international climate finance architecture.

This article reviews how that architecture currently works, where it succeeds, and where it does not. It covers the global carbon pricing landscape, the rise and credibility problems of voluntary carbon markets, the distribution of climate finance flows, the specific constraints facing developing economies, and what reforms would actually make a difference. The data are sourced from public information, such as State and Trends of Carbon Pricing by the World Bank; Global Landscape of Climate Finance by Climate Policy Initiative; OECD climate finance tracking; and ICAP, International Carbon Action Partnership.

2. Global Carbon Pricing Landscape: A Comparative Overview

Carbon pricing instruments fall into two broad categories. Emissions trading systems (ETS) set a cap on total emissions and allow covered entities to buy and sell allowances, so the quantity of reductions is fixed and the price is determined by the market. Carbon taxes set the price directly and allow the market to determine the quantity of reductions. Both approaches have genuine strengths. Neither has proven politically easy to implement at the scale required (Weitzman, 1974).

The EU ETS, launched in 2005 and now in its fourth phase, is the world's most developed compliance carbon market. It covers roughly 40% of EU emissions across power generation, heavy industry, aviation, and maritime shipping. The introduction of the Market Stability Reserve made it possible to increase the cap enough to ensure that the cost per ton was at least around EUR 100 in the beginning of 2023, before dropping to EUR 60 by the end of 2023. By 2025, the average auction price stood at EUR 73.43 while the secondary market prices were around EUR 74.35. The annual income was EUR 43.2 billion, and the cumulative income amounted to EUR 265.7 billion. Most of this is allocated to the EU Innovation Fund and member states' climate policies. It remains, however, an outlier.

Table 1 compares major carbon pricing schemes currently operating or under development. The variation is striking: prices range from USD 3 per tonne in Mexico to USD 137 in Sweden. Revenue generation is heavily concentrated. Coverage rates differ widely by design choice. And the geographic picture shows that most of the developing world, including the bulk of sub-Saharan Africa, Southeast Asia, and the Middle East, sits entirely outside any explicit carbon pricing framework.

Table 1. Major Carbon Pricing Schemes Worldwide (2025–2026)

Jurisdiction	Instrument	Price (USD/tCO ₂ e)	Coverage (% GHG)	Revenue 2025 (USD bn)	Status
European Union	ETS (Cap & Trade)	~74	40%	~48.9	Operational
Sweden	Carbon Tax	~137	40%	~2.5	Operational
Canada	Carbon Levy + OBPS	~65	80%	~7.2	Operational
China	National ETS	~10	80%	~1.5	Expanding
Colombia	Carbon Tax	~6	23%	~0.2	Operational
South Africa	Carbon Tax	~10	80%	~0.3	Phase 2 (2026)
Mexico	Carbon Tax (pilot)	~3	40%	~0.1	Limited
India	Carbon Credit Trading Scheme	~5	~30%	~0.4	Developing
Japan	GX-ETS	~10-15	~50%	~0.5	Mandatory
Vietnam	ETS (pilot)	~5-8	~15%	~0.1	Pilot (2025-2028)

Source: World Bank (2026), State and Trends of Carbon Pricing; ICAP (2026), Emissions Trading Worldwide; author's compilation.

Three findings from Table 1 deserve particular attention. First, the price gap between the cheapest and most expensive schemes remains more than 45-fold. That gap is not merely an academic curiosity: it creates real incentives to relocate emissions-intensive production to less regulated jurisdictions, a phenomenon economists call carbon leakage. It also implies that multinational companies operating across national boundaries are exposed to different cost structures for their carbon emissions, based on where they are located. Secondly, EU ETS raised revenues similar to those from all other listed programs put together in 2025, showing how centralized the current system is. Thirdly, coverage levels range between 15% in Vietnam (trial period) and 80% in China and South Africa, according to the sector(s) or gas(es) covered by the pricing regime.

The China National ETS expanded substantially in 2025, covering the cement, steel, and aluminium industries that were initially not included in the scheme, which was only covering the power sector at first. This resulted in about 1,500 more entities joining the ETS scheme, bringing total coverage to around 8 billion tons of CO₂ equivalent – 80% of China's national emissions of CO₂, up from the previous level of 5 billion tons or 40% coverage – accounting for roughly 15% of global emissions (ICAP, 2025; Transition Asia, 2025).

India's CCTS, illustrated in Table 1 below, marks one of the major emerging market dynamics. Since the beginning of fiscal year 2025-26 on 1 April 2025, approximately 490 entities across seven energy-intensive industries are covered, including aluminum, cement, chlor-alkali, pulp and paper, petroleum refining, petrochemicals, and textile manufacturing (ICAP, 2026). In contrast to classic cap-and-trade schemes, the Indian CCTS takes an intensity-based approach by rewarding companies with CCCs for surpassing emissions-intensity benchmarks compared to being operated on a strict cap on emissions..

Japan's GX-ETS entered its compulsory stage on 1 April 2026, applying to over 700 firms and 50 percent of greenhouse gas emissions at the national level (524 million tCO₂e). The ETS piloting period in Vietnam was established for 2025-2028.. By 2030, the adoption of all initiatives currently in development would lead to roughly a third of world GHG emissions being regulated through carbon pricing.

A simple revenue efficiency index--defined here as annual revenue per unit of GHG coverage (USD billion per percentage point of national emissions covered)- further illustrates the disparity across schemes. Dividing the 2025 revenue figures in Table 1 by each scheme's coverage share yields the following: Sweden generates approximately USD 0.063 billion per percentage point of coverage, the EU ETS approximately USD 1.08 billion, Canada approximately USD 0.090

billion, and China approximately USD 0.019 billion. The developing country schemes in Table 1-- Colombia, South Africa, Mexico, India, and Vietnam--average approximately USD 0.007 billion per percentage point, roughly one-fifteenth the EU rate and one-quarter the Canadian rate. This author-computed index is not a measure of policy effectiveness, since revenue levels depend on price, coverage scope, and economic size simultaneously. It does, however, illustrate that the fiscal yield from carbon pricing in developing economies remains an order of magnitude below that of leading programmes, limiting the domestic resources available for green transition investment.

3. Voluntary Carbon Markets: Potential and Credibility Challenges

The voluntary carbon market allows companies and individuals to purchase credits to offset emissions they cannot yet eliminate. After 2020, it saw rapid growth and reached roughly USD 2 billion in terms of transaction value in 2022 due to the influx of companies pledging their commitment towards net zero emissions. McKinsey (2021) analysts had predicted that this market may grow to USD 50 billion by 2030. Following that, some credibility issues surfaced, and the market shrank considerably. In 2025, the total transaction value of the voluntary carbon credit market was estimated at about USD 1.68 billion, with predictions that this market may be worth up to USD 32.44 billion by 2035 at a compound annual growth rate of 34.8% (InsightAce Analytic, 2026).

Credit types range from avoided deforestation (REDD+) and renewable energy to methane capture, cookstove programmes, and newer removal approaches such as direct air capture and biochar. Most nature-based and community projects are hosted in developing countries, which is why voluntary markets are often described as a private finance channel for places public money does not reach. Whether they actually function that way is a different question.

In this regard, the issue of the verifiability of REDD+ credits is particularly controversial. In their paper published in *Conservation Biology*, Guizar-Coutino et al. (2022) used a pixel matching approach to assess the efficacy of 43 REDD+ projects certified by Verra and determined that REDD+ projects have helped to avoid deforestation at 47% in the period of the first five years of their existence, showing better performance in areas with high levels of deforestation. Yet in further coverage, the results of the study were used to compare the projects' real impact with the predictions made prior to the implementation of REDD+, which resulted in conclusions about the fact that around 94% of credits do not match the expected emission reductions. The issue has had considerable weight in the reduction in trading volumes in the voluntary market through 2023. It clearly shows the conflict between project developers' overoptimistic predictions and the credits granted based on the comparison with registered baselines.

The institutional response moved quickly. The Integrity Council for the Voluntary Carbon Market (ICVCM) released its Core Carbon Principles in 2023, setting minimum standards on additionality, permanence, measurability, and verifiability (ICVCM, 2023). The Voluntary Carbon Markets Integrity Initiative (VCMI) published guidance for buyers on how to make defensible climate claims (VCMI, 2023). Article 6.4 of the Paris Agreement, once operational, is intended to add an UN-supervised layer with authorization and corresponding adjustment requirements. Whether all this is sufficient remains genuinely uncertain. The voluntary market has a structural tension: buyers want affordable credits, which pushes toward credits that just clear the bar rather than credits that clearly work. On balance, the reform trajectory is moving in the right direction, but the pace is insufficient: without mandatory minimum quality thresholds enforced at the point of sale, the incentive to supply low-quality credits will persist regardless of how robust the certification frameworks become. The voluntary market is therefore unlikely to function as a reliable substitute for public climate finance in the near term. This credibility deficit, combined with the geographic concentration of voluntary finance, connects directly to the broader shortfalls in tracked climate finance flows examined in the following section.

4. Climate Finance Flows and Financing Gaps

Total tracked global climate finance reached an all-time high of USD 1.9 trillion in 2023, and early data indicates that annual flows exceeded USD 2 trillion for the first time in 2024 (CPI, 2025). That figure is often cited as evidence of progress, and it does represent progress. It is also, depending on which estimate one uses, somewhere between one-quarter and one-half of the USD 4 to 8 trillion annually required through 2030 to reach Paris Agreement goals. The gap is not narrowing fast enough.

Where that money goes matters as much as how much there is. Around 90% of tracked climate finance went to high-income countries and China in 2023. Sub-Saharan Africa, whose per-capita emissions are a fraction of those in the countries generating most of the capital, received less than 3% (CPI, 2023). Private finance represents about 51% of total finance and, for the first time, went above USD 1 trillion in 2023, surpassing public finance. Nevertheless, it appears that there is still a huge gap among emerging economies, as cheap finance remains a hindrance not only for domestic but also private climate finance (CPI, 2025). International climate financing provided in 2023 to emerging and developing economies totaled \$196 billion, where 78% of the amount came from the public sector.

The adaptation finance dilemma is the major challenge that the international community faces. According to figures published as of 2023, adaptation finance raised stood at about USD 65 billion; however, this figure can be underestimated as a result of difficulties associated with assessing it. The United Nations Environment Program (UNEP) explains that USD 310 billion yearly needs to be spent on adaptation to climate change in order for developing nations to adapt to this phenomenon until 2035. Developing nations provided only USD 25.9 billion to developing nations in terms of adaptation finance in 2023 in comparison to USD 27.9 billion in 2022. It means that developed countries are falling short USD 285 billion yearly, and the burden of such expenses is borne by nations that are the least culpable in this issue.

The NCQG on climate finance was agreed upon at the COP29 in 2024. This involved a bold aim of raising USD 300 billion per year from the developed countries to developing countries by 2035, and a bolder target of raising USD 1.3 trillion per year through all means (UNFCCC, 2024). The Baku to Belem Roadmap that is to be formulated through the NCQG will seek to devise methods for changing multilateral finance, access climate finance, build domestic capabilities, and open up huge investment potential through six key imperatives: energy transition, adaptation and resilience, loss and damage, natural capital, just transition, and cities (CPI, 2026). Many developing country delegations considered the headline USD 300 billion figure too low, particularly since much of it is expected to be in the form of loans. The private mobilization component is an aspiration rather than a guarantee. The gap between what was agreed and what is needed remains large.

5. Structural Constraints Facing Developing Economies

The typical challenges faced by developing countries include institutional weakness, underdeveloped financial markets, and unreliable governance, which together account for why the nations that would benefit the most from carbon trading are farthest away from joining such systems. The term "developing economies," however, is far from monolithic.

A useful working typology distinguishes three tiers. The first comprises large emerging economies--Brazil, India, South Africa, Indonesia, China - that have functioning financial systems, nascent or expanding domestic carbon markets, and improving institutional capacity; their primary barrier is price adequacy and market integration, not system absence. The second tier includes middle-income countries such as Colombia, Morocco, and Vietnam that have MRV frameworks under development, active engagement with international carbon finance, and moderately stable governance; for these countries, targeted capacity building and blended finance instruments can unlock significant mitigation potential within a five-to-ten-year horizon. The third

tier--comprising much of sub-Saharan Africa and the smaller island developing states--faces the full constellation of constraints simultaneously: no domestic carbon pricing, minimal MRV capacity, shallow financial markets, and high governance risk. These countries require grant-based instruments and concessional technical assistance before market-based mechanisms become relevant at all. The reforms discussed in Section 6 are most urgently needed for the third tier, but the sequencing differs by tier.

Participation in Article 6 of the Paris Agreement requires a country to maintain a credible national MRV system, a functioning carbon registry, and the technical capacity to apply complex corresponding adjustment rules. Many developing countries do not have these things, and building them is neither cheap nor quick. The UNFCCC's Paris Committee on Capacity-Building, bilateral technical assistance programmes, and multilateral development bank (MDB) support all help, but funding for capacity building has consistently fallen short of what is actually needed. The result is that the countries with the most cost-effective mitigation potential are often the least able to monetize it through international carbon markets.

Financing becomes another challenge added to these problems. As pointed out by the International Monetary Fund (IMF, 2023), financing renewable energy projects is two to three times more expensive in sub-Saharan Africa compared to Western Europe due to issues of currency risk, political risk premiums, and immature local capital markets, thereby diverting climate finance from poor to rich markets.

Governance constraints compound both of the above. Long-lived renewable energy assets need regulatory stability. Investors need to be confident that tariff agreements will hold, that contracts are enforceable, and that the rules will not change arbitrarily between financial close and the end of a 20-year project life. In many developing countries, that confidence is hard to establish. The response to governance risk is higher return requirements, which prices out projects that would otherwise be viable. Breaking this cycle requires institutional reform over time, which is exactly the kind of investment that yields no near-term political reward.

6. Policy Reforms and Recommendations

Four reform areas would make the most difference. None of them is new. All of them are moving too slowly.

Carbon price convergence and border adjustment. A 45-fold spread in carbon prices across jurisdictions is not a minor inefficiency. It creates real incentives for carbon leakage and real competitive distortions in traded goods. The EU Carbon Border Adjustment Mechanism (CBAM), fully phased in from 2026, targets leakage in selected industrial sectors, but it needs to be designed carefully. The literature identifies three principal design tensions (Cosbey et al., 2019; Mehling et al., 2019). First, sectoral coverage: CBAM initially covers steel, cement, aluminium, fertilizers, electricity, and hydrogen--together responsible for a significant share of trade-exposed emissions--but excludes sectors such as chemicals and plastics where leakage risk is also substantial. Expanding coverage increases environmental integrity but also administrative complexity. Second, the equivalence determination problem: CBAM requires calculating the embedded carbon content of imported goods, which demands product-level emissions data that many exporting countries cannot yet provide; this asymmetry may effectively function as a non-tariff barrier. Third, revenue disposition: under current EU proposals, CBAM revenues flow to the EU general budget rather than to climate finance for affected trading partners. Applied without revenue recycling, it functions as a trade barrier against developing country exporters who had little to do with creating the climate problem. A portion of CBAM revenues should be directed to climate finance for affected developing nations. This is both equitable and politically necessary for the mechanism's long-term legitimacy.

MDB reform and blended finance. The G20 Independent Expert Group (2023) found that multilateral development banks could increase climate lending by USD 300 to 500 billion per year

without putting their credit ratings at risk, mainly by using their capital more efficiently and transferring more risk to capital markets. That capacity is sitting unused. What is needed is deployment of guarantees, first-loss tranches, and political risk insurance that make developing country projects attractive enough to draw in private investors who are currently uncommitted. The Baku to Belem Roadmap emphasizes MDB reform as a critical pillar, calling for intensified engagement on climate finance through a strategic approach that recognizes and amplifies their catalytic role in providing and mobilizing capital (CPI, 2026). Commitments in communiqués must be operationalized through specific deal structures.

Capacity building for MRV and Article 6. The technical requirements for carbon market participation should not function as a barrier to entry for the countries with the most to gain. Standardized MRV methodologies, open-source registry software, and adequately funded regional technical assistance centers can reduce the fixed costs of establishing national carbon accounting infrastructure. This should be financed through assessed contributions to the UNFCCC process rather than voluntary bilateral programmes that are subject to donor political cycles. Operationalization of Article 6 provisions at COP29 in 2024 through decisions on both articles, 6.2 and 6.4, offers guidelines for carbon trading internationally, yet it requires sustained assistance for developing countries to engage (OECD, 2025).

Adaptation re-balancing. Less than 10 percent of the overall climate finance allocated to adaptation does not reflect their relative need but rather donor preferences for investments in mitigating measures that are tangible and tradable. Adaptation windows within the Green Climate Fund and MDBs should be significantly widened to include simplification in accessing such facilities as well as using grants-based mechanisms. According to the UNEP Adaptation Gap Report 2025, NCQG alone is inadequate for financing adaptation projects, and the Baku to Belem Roadmap must offer ways to bridge the adaptation finance gap equitably without making developing countries vulnerable (UNEP, 2025).

7. Conclusions

The global carbon pricing landscape is fragmented, underpowered, and inequitable. Eighty-seven instruments are now in operation worldwide, generating more than USD 107 billion annually, and total tracked climate finance has exceeded USD 2 trillion per year. Those numbers represent genuine progress. They also represent a fraction of what is needed, concentrated in places that need it least.

The 45-fold price gap documented in Table 1 is not a transitional problem. Without deliberate policy action, carbon leakage risk will make harmonization harder over time, not easier. It is not that low-income countries are irrelevant to carbon pricing schemes, but rather that they lack the capacity to join such initiatives in terms of their institutions, financing, and governance structures.

The barriers facing developing economies are real but not fixed. Targeted MDB reform, serious capacity building finance, CBAM revenue recycling, and a genuine re-balancing of mitigation and adaptation spending could address all three constraint categories identified in this paper. The analysis suggests these reforms are both technically feasible and economically rational, given that the marginal cost of emissions reductions is often lowest precisely in the countries currently furthest from the carbon pricing frontier.

The timeframe for achieving Paris Agreement (UNFCCC, 2015) goals is narrowing. The economics of delay are well documented. This analysis adds the observation that the distribution of that delay's cost is as much a policy choice as the delay itself. Building an international carbon market and climate finance architecture that works for developing economies is not a question of charity. It is a condition of the system's credibility and, ultimately, its effectiveness. Future research should examine the political economy of price convergence and the conditions under which concessional finance is most effective at mobilizing private capital in high-risk jurisdictions.

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Between Loyalty and Performance: A Conceptual Framework for Understanding Informal Network Influence on HRM in the South Caucasus

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Abstract

This paper develops a conceptual framework to understand how informal social networks shape human resource management (HRM) practices in the South Caucasus, drawing on theoretical work on organizations in Georgia, Armenia, and Azerbaijan. Drawing on institutional theory, social capital theory, and comparative HRM scholarship, the paper identifies a structural tension, termed the loyalty-performance tension, between the relational logic embedded in post-Soviet informal networks and the meritocratic logic prescribed by mainstream HRM theory. The framework proposes that this tension is governed by four interacting determinants: the quality of the institutional environment, the depth of network embeddedness, professional HRM competence, and resource availability. The paper argues that loyalty logic in HRM is not a cultural residue awaiting dissolution through institutional modernization but a rational, adaptive governance mechanism that persists because formal institutions do not yet provide equivalent guarantees of reliability, competence, or trustworthy conduct. Five theoretically grounded propositions are advanced, each carrying specific implications for comparative HRM theory, institutional scholarship, and practitioners engaged in people management reform across post-Soviet contexts. The paper concludes by establishing a research agenda for empirical investigation of the framework across the South Caucasus and cognate settings.

Keywords: *informal networks; HRM; South Caucasus; institutional theory; social capital; post-Soviet organisations; loyalty; performance management; transitional economy; conceptual framework*

1. Introduction

The dominant tradition in human resource management scholarship rests on a set of universalist premises that have rarely been interrogated against the institutional realities of post-Soviet economies. Hiring decisions, this tradition holds, should reflect demonstrable competence assessed through standardized processes; promotion should reward observable performance against measurable criteria; and the personal relationships of managers and owners should remain formally separate from the organizational decisions they make about who is recruited, advanced, and retained. These premises carry an embedded institutional assumption that the formal systems required to make performance-based HRM work are sufficiently developed to bear the governance weight that meritocratic logic places upon them. In the South Caucasus, that assumption encounters sustained and revealing friction.

Organizations in Georgia, Armenia, and Azerbaijan operate within institutional environments that depart substantially from the model underpinning mainstream HRM theory. Labor market information is expensive to acquire and difficult to verify independently. Professional credentials carry variable reputational weight across institutions of markedly unequal quality. Employment contracts exist in formal terms, but their legal enforcement remains slow, costly, and uncertain in outcome. Against this backdrop, informal social networks the dense, historically rooted, and affectively charged webs of kinship, friendship, shared educational experience, regional affiliation, and accumulated mutual obligation that characterize social organization across the region, perform governance functions that formal institutions do not yet reliably supply. They circulate trusted information about candidates' character and reliability. They create accountability structures that survive the termination of formal employment. They bind employers and employees through obligations of loyalty and reciprocity that make relational defection socially costly in ways that legal contracts alone cannot replicate.

This paper takes that observation as its theoretical point of departure. Its purpose is not to report empirical findings but to develop a conceptual framework of the loyalty-performance tension that provides a theoretically grounded and analytically tractable basis for understanding why informal networks shape HRM decision-making in the South Caucasus, how that influence operates across different organizational and institutional contexts, and under what conditions the balance between loyalty logic and performance logic shifts. In doing so, it makes three contributions. First, it integrates institutional theory, social capital scholarship, and comparative HRM research into a coherent explanatory framework that advances beyond existing accounts of HRM in transitional economies. Second, it proposes five theoretically grounded propositions that specify the conditions governing the loyalty-performance balance, providing a foundation for systematic empirical investigation. Third, it establishes a research agenda that identifies the most productive directions for future comparative and longitudinal work in this underresearched region.

The South Caucasus merits theoretical attention for reasons that extend well beyond its geographic boundaries. It constitutes a concentrated site of institutional variation, three post-Soviet states at different stages of formal institutional development, with different histories of Soviet organizational culture, different trajectories of post-independence reform, and different degrees of integration into international economic and regulatory frameworks, which makes it an unusually productive context for examining how institutional conditions shape organizational behavior. What the South Caucasus makes visible with analytical clarity, the loyalty-performance tension makes legible across a much wider range of transitional- and developing-economy contexts where formal institutions coexist uneasily with deeply embedded informal governance mechanisms.

1.1. Scope and Positioning of the Paper

This paper is explicitly positioned as a conceptual contribution. It does not report primary empirical data, and its propositions are advanced as theoretically derived claims to be tested in future empirical research rather than as findings drawn from original fieldwork. This positioning reflects a deliberate methodological choice: the loyalty-performance framework is sufficiently novel, and the South Caucasian context sufficiently undertheorised, that a rigorous conceptual elaboration of the framework has independent scholarly value prior to its empirical validation. The paper draws on published organizational research, grey literature from international development organizations with extensive regional engagement, and a synthesis of comparative HRM and institutional scholarship to ground its theoretical argument in observable patterns without overstating the evidentiary basis of its claims.

1.2. Research Questions

The paper addresses three conceptual questions that together frame the loyalty-performance framework:

RQ1: What theoretical mechanisms explain the persistence of informal network influence on HRM decision-making in low-institutional-trust environments such as the South Caucasus?

RQ2: What are the primary determinants that govern the relative predominance of loyalty logic versus performance logic in HRM decision-making, and how do these determinants interact?

RQ3: Under what conditions does the balance between loyalty logic and performance logic shift, and what mechanisms drive that shift?

2. Theoretical Foundations

The loyalty-performance framework draws on three streams of scholarship that have not previously been integrated in a systematic analysis of HRM in post-Soviet settings: institutional theory, social capital and network theory, and comparative HRM research. This section reviews each tradition, identifies its specific contribution to the framework, and establishes the theoretical basis for its integration.

2.1. Institutional Theory: Formal Weakness and Informal Governance

Institutional theory provides the foundational lens for explaining why HRM practices vary systematically across organizational environments and why informal governance mechanisms persist alongside formal ones in transitional settings. DiMaggio and Powell's seminal account established that organizations within a shared field exhibit structural similarity not because convergent forms are necessarily more efficient but because they confer legitimacy within the institutional environments in which organizations seek resources, recognition, and social approval (DiMaggio and Powell, 1983). Applied to HRM, this insight implies that the content of people management practices will reflect the logics operative in the institutional environments of the organizations in question, including informal logics, rather than converging on a universal efficiency-maximizing model irrespective of context.

North's distinction between formal and informal institutions carries particular weight for the present analysis (North, 1990). Where formal institutions are strong, codified, and consistently enforced, they provide the primary framework through which economic and organizational life is structured. Where they are weak, ambiguous, or unreliable, informal institutions, norms, conventions, and socially shared understandings enforced through reputation and relational obligation fill the governance space. North's critical insight, often understated in applications of his framework, is that informal institutions do not simply compensate for formal weakness: they develop their own internal logic, their own moral economy, and their own enforcement mechanisms that make them resistant to displacement even as formal institutional capacity grows.

Scott's three-pillar model extends this framework by disaggregating institutional influence into regulative, normative, and cognitive dimensions (Scott, 2001). Regulative institutions, laws, regulations, and enforcement mechanisms shape behavior through coercive sanctions. Normative institutions, professional standards, occupational norms, and role expectations shape behavior through obligation and appropriateness. Cognitive institutions' shared taken-for-granted assumptions about how things are done shape behavior through constitutive scripts that actors follow without conscious deliberation. In South Caucasian HRM, informal network governance operates across all three dimensions: network-based hiring is sometimes legally constrained (regulative), often professionally normalized (normative), and frequently taken for granted as simply the way recruitment works (cognitive). Understanding its persistence requires engaging with all three dimensions simultaneously.

Comparative institutionalism elaborates the macro-level conditions that generate different organizational configurations. Whitley's business systems framework demonstrated that national institutional arrangements in finance, labor markets, education, and the state produce systematically different patterns of firm governance and employment practice (Whitley, 1999). Hall and Soskice extended this to show that coordinated and liberal market economies generate fundamentally different HRM complementarities (Hall, Soskice, 2001). Nölke and Vliegenthart's dependent market economy category, characterized by weak domestic institutions, porous regulatory frameworks, and a high reliance on personal relationships for economic coordination, provides the closest institutional type for understanding organizational environments in the South Caucasus (Nölke and Vliegenthart, 2009). Yet this category was developed based on evidence from Central and Eastern Europe and requires modification to accommodate the distinctive Soviet institutional legacy and the post-independence trajectories of the South Caucasian states.

2.2. Social Capital and Network Theory: The Governance Logic of Informal Networks

Social capital theory explains the specific mechanisms through which informal networks perform governance functions that formal institutions cannot adequately supply. Bourdieu conceptualized social capital as the aggregate of resources, informational, material, and reputational, accessible through membership in durable networks of mutual acquaintance and recognition (Bourdieu, 1986). These resources are not merely personal assets but structural properties of network positions: actors embedded in high-quality networks gain systematic advantages in accessing opportunities, verifying information, and enforcing informal expectations that structurally peripheral actors cannot replicate through formal channels alone.

Coleman's account deepens this by focusing on the closure properties of dense networks (Coleman, 1988). Closed networks in which most members know one another and observe one another's conduct generate strong norms of reciprocity and powerful mechanisms of reputational sanction that create what Coleman termed social capital in the form of trustworthiness. An employee recruited through a closed network not only arrives with an implicit performance guarantee from the recommender but is also subject to a form of social control that extends beyond the formal employment relationship. Breaking the employer's trust means simultaneously damaging the recommender's reputation and one's own standing across the shared social network, a multilateral sanctioning mechanism that employment contracts in weak-enforcement environments struggle to replicate.

Granovetter's distinction between strong and weak ties provides the most directly applicable network theory for HRM analysis (Granovetter, 1973). Strong ties, the close, multiplex, emotionally intense relationships of kinship, longstanding friendship, and tight collegial bonds provide high-quality, trust-verified information about personal qualities and reliability. In South Caucasian HRM, strong-tie networks dominate recruitment and promotion decisions precisely because they supply the kind of information about character, loyalty, and reliability under pressure that formal credentials and interview processes in underdeveloped information environments cannot match. Weak ties provide access to a wider range of candidates but do not generate sufficient trust to resolve the reliability problem that drives network-based hiring in the first place.

The post-Soviet concept of *blat* illuminates the specific regional character of network governance. Ledeneva's foundational research established that *blat*, the informal exchange of favors and access that organized economic and social life under Soviet conditions, was not mere corruption but a fully elaborated social institution with its own moral economy, its own norms of obligation and reciprocity, and its own criteria of legitimate and illegitimate exchange (Ledeneva, 1998, 2006). Post-Soviet mutations of *blat* across Russia, Ukraine, and the wider former Soviet space have been extensively documented; their South Caucasian analogues the Georgian concept of *k'atsi*, the relational ethic of honour and mutual obligation; the Armenian *akhperut'yun*, the brotherhood of trusted mutual loyalty; the Azerbaijani *tanish*, acquaintance-based access and

favour exchange give informal network governance a culturally specific texture that generic social capital theory does not fully capture. These are not simply informal practices that happen to resemble blat: they are historically specific institutional formations whose internal logic and moral weight must be understood on their own terms if HRM scholarship is to engage productively with the organizational realities they shape.

2.3. Comparative HRM: The Limits of Universalism

Comparative HRM literature provides the third theoretical resource by documenting the systematic inadequacy of universalist HRM prescriptions when applied in environments lacking their institutional preconditions. The dominant tradition in HRM research, developed overwhelmingly from evidence gathered in North American and Western European organizations, has advanced a set of high-performance work system prescriptions whose universal applicability has been increasingly challenged by comparative and cross-cultural scholarship (Brewster, 1999; Wood and Ajnabi, 2010).

Research on HRM in post-Soviet and transitional economies has documented a persistent, analytically significant gap between formal HRM adoption and actual practice. Soulsby and Clark's longitudinal research in Central European enterprises demonstrated that Western HRM models introduced through foreign investment were selectively enacted, symbolically adopted, and domestically reconfigured in ways that reflected the persisting institutional and relational logics of the socialist period (Soulsby and Clark, 2007). Michailova and Worm's comparative analysis documented the ways in which personal network governance blat in Russia, guanxi in China shapes knowledge management and organizational behavior in ways that formal management systems neither anticipate nor adequately accommodate (Michailova and Worm, 2003). Collectively, this literature establishes that HRM in post-Soviet economies is not a lagging or underdeveloped version of Western HRM but rather a distinctive institutional configuration that requires its own theoretical framework.

The literature also reveals a critical gap: no published study has systematically theorized the mechanisms through which informal networks shape HRM across the South Caucasus as a regional unit, developed a framework that integrates institutional theory and social capital scholarship in the analysis of this dynamic, or advanced testable propositions that could guide comparative empirical research. The loyalty-performance framework developed in Section 3 is designed to fill precisely this gap.

2.4. Synthesis: Toward Integration

The three theoretical traditions converge on a set of shared insights that form the foundation of the loyalty-performance framework. First, from institutional theory, HRM practices reflect the governance logic of their institutional environments, and where formal institutions are weak, informal institutions bear the governance load. Second, from social capital theory: informal networks provide specific and substantive governance mechanisms, trust verification, reputational sanctioning, and relational accountability that are not merely symbolic substitutes for formal processes but functionally effective alternatives under specific institutional conditions. Third, from comparative HRM: universalist prescriptions for performance-based people management assume institutional preconditions that are absent or underdeveloped in post-Soviet settings, generating a systematic gap between formal adoption and actual practice that requires its own theoretical explanation rather than simple diagnosis as institutional underdevelopment.

3. The Loyalty-Performance Framework

This section fully develops the loyalty-performance framework. It defines the two competing logics, specifies the four determinants that govern their relative predominance, and advances five theoretically grounded propositions.

3.1. Defining the Two Logics

Performance logic treats HRM as a technical optimization problem whose solution lies in the design and administration of formal assessment, selection, and evaluation systems. It assumes that job-relevant competencies can be identified, operationalized, and measured through processes that are sufficiently reliable to override relational considerations in allocation decisions. Its institutional preconditions are demanding: reliable mechanisms for verifying credentials and references; enforceable employment contracts that protect both employer and employee interests against opportunistic behavior; labor market information systems that reduce search costs and the risk of adverse selection; and organizational capacity to design and administer performance assessments without generating social penalties that undermine their use. When these preconditions are met, performance logic produces HRM outcomes that are both technically efficient and socially legitimate. When they are absent or unreliable, performance logic becomes institutionally costly and practically fragile.

Loyalty logic treats HRM as a relational governance problem whose solution lies in cultivating and deploying personal trust networks. It assumes that the primary risk in people management is not technical incompetence but relational betrayal, the possibility that an actor without prior ties of shared history and mutual obligation will exploit informational asymmetries, renege on implicit agreements, or prioritize external interests over organizational loyalty. Its institutional logic is not irrational: in environments where formal contracts are difficult to enforce, and reputational information about unknown candidates is costly to verify, personal network ties provide governance guarantees through strong-tie trust, network closure, and reputational sanctioning that formal systems cannot match. Loyalty logic does not eliminate the risk of incompetence; it trades technical risk for relational assurance, accepting a narrower candidate pool in exchange for higher confidence in reliability and commitment.

The tension between these two logics is not a stable equilibrium but a dynamic, contextually variable, and organisationally consequential relationship. In any given organization, the relative weight of loyalty and performance logic in HRM decision-making reflects the interaction of four theoretically identified determinants, each of which is specified below and illustrated in Figure 1.

Figure 1. The loyalty-performance framework: four determinants and their directional effects on HRM orientation. [Figure to be produced from empirical data and inserted here.]

3.2. The Four Determinants

3.2.1. Institutional Environment Quality (IEQ)

Institutional environment quality refers to the degree to which formal governance mechanisms, such as contract enforcement, credential verification, labor market information, and dispute resolution, provide reliable and accessible alternatives to network-based trust in HRM decision-making. Where IEQ is high, the cost of performance logic falls: employers can verify credentials through formal channels, rely on contracts to govern the employment relationship, and access labor market information that reduces the informational advantage of personal networks. Where IEQ is low, these alternatives are unavailable or unreliable, and the relative cost-benefit ratio of loyalty logic improves correspondingly.

IEQ is not a single-country characteristic but varies across sectors, firm types, and regulatory domains within any given country. Georgian technology firms operating under international accounting standards and with access to internationally recognized certification systems face a different IEQ than Georgian family-owned retail enterprises whose employment relationships are governed primarily by informal understandings. This within-country variation is analytically important: it implies that HRM formalization can advance unevenly across sectors even within a single national institutional environment.

3.2.2. Network Embeddedness (NE)

Network embeddedness refers to the degree to which key HRM decision-makers are personally embedded in dense, trust-rich informal social networks whose members are potential candidates, recommenders, or relational stakeholders in employment decisions. High network embeddedness creates both capability and normative pressure to use those networks in HRM decisions: capability, because embedded actors have access to the trust-verified information that network governance provides; and normative pressure, because failing to use the network when a network-connected candidate is available carries social costs in the form of damaged relationships and reputational consequences that make network exclusion organisationally costly beyond purely informational considerations.

Network embeddedness is a property of individual decision-makers as well as of organizations. A founder-owner deeply embedded in regional kinship and business networks faces different HRM decision-making constraints than a professionally trained HR director in the same organization whose personal networks are less dense or differently constituted. This individual-level variation within organizations has important implications for understanding how the loyalty-performance balance is negotiated within firms and across them.

3.2.3. Professional HRM Competence (PHC)

Professional HRM competence refers to practitioners' knowledge of formal HRM methodologies, recruitment design, competency frameworks, performance appraisal, and structured interviewing, as well as their confidence in these methodologies' ability to generate reliable information for HRM decisions. PHC functions not merely as a technical resource but as a form of institutional confidence: the practitioner-level belief that formal processes can produce information reliable enough to justify performance-based decisions that override relational ones. Where PHC is high, practitioners are better equipped to challenge loyalty-logic decisions on professional grounds, to design formal processes that generate genuinely useful information, and to invoke professional standards as a legitimate alternative to relational governance.

PHC is developed through formal HRM education, professional certification, and experience with formal HRM systems within organizations. It is consequently distributed unevenly across the South Caucasian HRM practitioner population, with higher concentrations in internationally exposed sectors, larger organizations, and among younger practitioners who received their professional formation in the post-Soviet period. This uneven distribution generates predictable variation in the loyalty-performance balance across organizational types and generational cohorts.

3.2.4. Resource Availability (RA)

Resource availability refers to the financial, human, and informational resources available to organizations for the design and maintenance of formal HRM systems. Formal recruitment is resource-intensive: advertising positions, designing assessments, conducting structured interviews, verifying credentials, and administering formal onboarding all require financial investment and professional time that network-based alternatives economize. Where RA is constrained as it frequently is in small and medium enterprises in the South Caucasus, the cost differential between formal and network-based HRM is practically significant and shapes practitioners' choices independently of normative preferences. An employer who is genuinely committed to performance-based HRM in principle may, in practice, be structurally constrained to use network-based alternatives by the resource costs of maintaining a formal system.

3.3. Theoretical Propositions

Drawing from the four-determinant framework and the theoretical foundations reviewed in Section 2, five propositions are advanced. These are offered as theoretically grounded claims to be subjected to systematic empirical investigation rather than as empirically established findings.

Table 1. Summary of theoretical propositions and their empirical implications.

P	Proposition	Primary Empirical Implication
P1	Organizations operating in weaker formal institutional environments will exhibit significantly greater reliance on loyalty logic in HRM decisions, <i>ceteris paribus</i> .	IEQ will be negatively associated with the predominance of loyalty logic across comparative samples.
P2	Higher network embeddedness among key HRM decision-makers will be positively and significantly associated with the predominance of loyalty logic, independently of the quality of the institutional environment.	NE will retain significant predictive power for HRM orientation after controlling for IEQ.
P3	Greater professional HRM competence will be positively and significantly associated with performance-logic orientation, via institutional confidence in the reliability of formal processes.	PHC will be the strongest positive predictor of performance-logic orientation among the four determinants.
P4	Resource constraints will moderate the relationship between institutional environment and HRM orientation, restricting the practical viability of performance logic even in relatively stronger institutional environments.	The IEQ-HRM orientation relationship will be significantly weaker in resource-constrained organizations than in resource-adequate ones.
P5	The loyalty-performance balance will shift toward greater performance-logic orientation as a function of international sector exposure, organizational scale, and generational cohort, three mechanisms that simultaneously develop PHC, reduce NE, and improve effective IEQ.	Internationally exposed, larger, and younger-led organizations will show significantly higher performance-logic orientation than domestically oriented, smaller, and senior-led counterparts.

Note. IEQ = Institutional Environment Quality; NE = Network Embeddedness; PHC = Professional HRM Competence; P = Proposition.

3.4. Dynamic Properties of the Framework

The loyalty-performance framework is not a static equilibrium model but a dynamic account of how the balance between two governance logics shifts as the four determinants change. Three mechanisms of dynamic change deserve particular theoretical attention.

International sector exposure serves as a combined mechanism that simultaneously develops PHC through exposure to internationally standardized HRM practices, reduces effective NE by expanding the range of candidates considered legitimate beyond existing personal networks, and improves effective IEQ by embedding organizations in international regulatory and credentialing frameworks that are more reliable than domestic equivalents. The technology, financial services, and logistics sectors across all three South Caucasian countries provide observable instances of this mechanism in operation.

Organizational scale functions as a second mechanism. As organizations grow beyond the size at which founder networks can adequately cover all key personnel decisions, the information costs of network-only recruitment rise, and the case for formal HRM systems becomes more compelling on purely practical grounds. The transition from founder-led to professionally managed enterprise is a critical juncture at which many South Caucasian organizations negotiate the loyalty-performance balance, often with significant internal conflict between relational and meritocratic governance principles.

Generational change constitutes the third and potentially most structurally consequential mechanism of framework dynamics. Younger professionals across the South Caucasus, those who received their education and formed their career expectations in the post-Soviet period, who have had greater exposure to international professional norms through education abroad, digital platforms, and multinational employers, tend to express stronger preferences for meritocratic evaluation and transparent career development than their senior colleagues. Whether these generational preferences will translate into sustained HRM transformation or be absorbed and moderated by the normative and reputational pressures of network embeddedness as younger practitioners move into positions of organizational authority is a question the framework identifies as one of the most important for future longitudinal research.

4. The South Caucasian Institutional Context

The loyalty-performance framework is developed as a general conceptual tool applicable across any low-institutional-trust environment. This section grounds the framework in the specific institutional realities of the South Caucasus, demonstrating both why this context is a particularly productive site for its application and how the region's distinctive institutional configuration shapes the expression of the four determinants.

4.1. Soviet Institutional Legacies

Any theoretically serious account of HRM in the South Caucasus must engage with the Soviet institutional legacy not as a historical footnote but as a constitutive force that continues to shape organizational behavior across the region. The Soviet workplace was, among other things, a site of intensive network formation under conditions of structural scarcity. The allocation of resources, the assignment of positions, the management of career trajectories, and the navigation of everyday organizational life all depended on informal relationships that supplemented and frequently substituted for the formal mechanisms of socialist planning and administration.

Soviet enterprises were formally organized along bureaucratic lines with defined hierarchies, job classifications, and planned labor allocation. In practice, managers at every level depended on informal networks to fulfill plan targets, manage production bottlenecks, secure scarce inputs, and protect their units from the unpredictable demands of the planning apparatus. Workers depended on managerial patronage and collegial solidarity for access to housing, consumer goods, vacation allocations, and career advancement. The result was a dense web of reciprocal obligations, informal understandings, and network-mediated coordination that functioned in parallel with, and often more effectively than, the formal organizational structure. When the Soviet Union collapsed, these networks did not dissolve. Amid the acute institutional uncertainty and economic contraction of the 1990s, they intensified in importance, becoming primary mechanisms of survival, coordination, and access to opportunity in environments where formal institutions had been simultaneously dismantled and had not yet been reconstructed.

4.2. Contemporary Institutional Conditions Across the Three Countries

Three decades after independence, the institutional landscapes of Georgia, Armenia, and Azerbaijan have undergone substantial but uneven transformation, generating within-region variation that the loyalty-performance framework must accommodate.

Georgia's post-2003 Rose Revolution reform program produced significant gains in formal institutional quality, particularly in reducing petty corruption, improving regulatory predictability,

and strengthening property rights enforcement. The World Bank's governance indicators consistently position Georgia among the strongest performers in the post-Soviet space on rule of law and government effectiveness dimensions (World Bank, 2025). Nevertheless, the PULSE public sector accounting assessment notes a persistent gap between formal standards adoption and the quality of practical implementation, a pattern consistent with the framework's prediction that institutional reform is necessary but not sufficient for the formalization of practice (World Bank, 2025). In HRM terms, Georgian organizations, particularly in Tbilisi and in internationally exposed sectors, show meaningful movement toward mixed-logic orientations, while domestic SMEs and regional enterprises retain predominantly loyalty-logic patterns.

Armenia's 2018 Velvet Revolution initiated a reform trajectory with notable early progress in judicial independence and anti-corruption enforcement, though the pace and depth of institutional change have been moderated by geopolitical pressures and economic constraints. The Armenian private sector is characterized by a significant diaspora business presence that introduces international HRM norms through returnee entrepreneurs and diaspora-funded enterprises, creating a distinctive mechanism of HRM norm transfer that has no precise parallel in the other two countries. This diaspora channel is an important theoretical nuance that comparative studies of HRM formalization in Armenia must incorporate.

Azerbaijan presents a more statist developmental configuration, in which the relationship among formal institutions, business networks, and state authority is more tightly intertwined than in the other two countries. The dominant role of state-connected enterprises in the economy and the personalized character of business-state relations create an institutional environment in which network-based governance is not merely a substitute for weak formal institutions but is actively reproduced through the incentive structures of the political economy itself. HRM formalization in Azerbaijan faces not only the institutional capacity constraints that affect all three countries but an additional layer of network-based governance that is positively reinforced rather than merely tolerated by the dominant institutional order.

4.3. Cross-Cutting Regional Patterns

Despite these country-specific differences, three institutional patterns are sufficiently consistent across the region to warrant theoretical treatment as regional characteristics rather than country-specific anomalies. First, labor market information systems remain underdeveloped relative to Western European comparators across all three countries, maintaining the informational advantage of personal networks in candidate assessment. Second, professional credentialing in HRM and related fields carries variable reputational weight, with wide quality disparities between elite and non-elite educational institutions that are frequently opaque to employers relying on formal credentials. Third, the social and cultural expectations of network reciprocity the normative pressure to hire and promote through one's relational networks, are sufficiently embedded across all three contexts to constitute a regional institutional feature rather than a purely individual attitude. These three patterns collectively sustain the conditions under which loyalty logic remains rational, normatively compelling, and practically entrenched.

5. Discussion: Theoretical and Practical Contributions

The loyalty-performance framework advances theoretical understanding of HRM in post-Soviet and transitional economies in three principal ways, each of which carries practical implications for HRM reform design.

5.1. Reframing Informal Network Influence as Institutional Adaptation

The framework's most fundamental theoretical contribution is the reframing of informal network influence on HRM from a governance failure to an institutional adaptation. The dominant discourse in international development organizations and comparative HRM policy treats network-based hiring and promotion as a form of nepotism to be eliminated through institutional reform, training, and cultural change. This framing is not only theoretically inadequate; it

mischaracterizes the institutional logic of loyalty network governance and is practically counterproductive, generating reform interventions that practitioners experience as attacks on legitimate governance mechanisms rather than improvements in organizational effectiveness.

The framework argues, on theoretical grounds, that loyalty logic is rational under the institutional conditions prevailing across much of the South Caucasus: it provides governance guarantees that formal institutions do not yet reliably supply, at lower transaction costs than formal alternatives. This does not mean that loyalty logic is optimal; its costs, including the systematic exclusion of talented candidates from existing networks and the organizational rigidities generated by loyalty obligations, are real and significant. But understanding those costs and addressing them requires engaging honestly with the governance functions that loyalty logic performs, rather than treating its persistence as evidence of cultural backwardness or institutional failure.

5.2. The Four-Determinant Model and Comparative HRM Theory

The four-determinant model IEQ, NE, PHC, and RA provides a theoretically grounded and empirically tractable framework for understanding variation in HRM orientation both across organizations and over time. This model advances existing comparative HRM theory in two important ways. First, by treating network embeddedness as an independent determinant rather than a symptom of institutional weakness, it establishes that HRM formalization requires explicit engagement with the social structure of decision-making networks, not simply improvement in formal institutional quality. Second, by including resource availability as a determinant, it captures the material dimension of the loyalty-performance tension that normative reform discourse consistently neglects. Practitioners cannot implement formal HRM systems they cannot afford, regardless of their normative commitments.

The framework also contributes to the varieties of institutionalism literature by identifying a specific configuration of weak IEQ combined with high NE, low PHC, and constrained RA that produces a predominance of loyalty logic regardless of formal regulatory mandates. This configuration is not unique to the South Caucasus; it characterizes a wide range of transitional and developing-economy contexts in which informal network governance persists alongside formal HRM adoption. The loyalty-performance framework, therefore, has explanatory reach well beyond its regional derivation.

5.3. Implications for HRM Reform Practice

The framework generates a set of practical implications for HRM reform that differ substantively from conventional prescriptions. Effective HRM reform in the South Caucasus requires simultaneous progress across all four determinants, not sequential improvement in any single dimension. Training programs that develop formal HRM competence are necessary but insufficient without complementary institutional and resource conditions. Regulatory reform that improves formal contract enforceability is necessary but insufficient if network embeddedness retains independent normative force. Resource provision that reduces the cost of formal HRM systems is necessary but insufficient if practitioners lack the competence to use those systems effectively.

The most practically significant implication of the framework is the case for phased, engagement-based reform that works with the governance functions of informal networks rather than seeking to replace them through regulatory prescription. This means, in concrete terms: building formal credentialing systems that provide the trust-verified information that networks currently supply through personal vouching; developing professional HRM associations that create new normative frameworks and identities capable of competing with relational governance logics; investing in accessible legal mechanisms for employment contract enforcement that reduce the cost of performance-based dismissal; and designing capacity-building programmes that target not

only HRM technical skills but the institutional confidence and professional authority that make formal processes normatively legitimate in organisational decision-making contexts.

5.4. Limitations of the Conceptual Framework

The loyalty-performance framework has three limitations that future empirical research must address. First, it treats the four determinants as analytically separable for purposes of theoretical exposition while acknowledging that they interact in complex ways that the framework specifies only at the level of directional effects. The precise functional form of these interactions, whether they are additive, multiplicative, or threshold-conditional, requires empirical investigation. Second, the framework draws on theoretical reasoning and published organizational research rather than primary empirical data, so its propositions are theoretically grounded but not empirically validated. Third, the framework's dynamic propositions about the mechanisms underlying shifts in the loyalty-performance balance are speculative in the absence of longitudinal evidence. All three limitations identify productive directions for future empirical research rather than invalidating the framework's conceptual contribution.

6. Research Agenda and Conclusions

6.1. Empirical Research Agenda

The loyalty-performance framework generates a structured research agenda organized around the five theoretical propositions and the three dynamic mechanisms identified in Section 3. Table 2 summarises the most productive directions for empirical investigation, specifying for each the appropriate methodology, the key measurement challenges, and the theoretical question it would resolve.

Table 2. Empirical research agenda derived from the loyalty-performance framework.

Research Priority	Methodology	Key Measurement Challenge	Proposition Addressed
Cross-national comparative survey of HRM orientation across Georgia, Armenia, and Azerbaijan	Structured survey, chi-square, logistic regression	Measuring loyalty vs. performance orientation without social desirability bias	P1, P2, P3, P4
Qualitative study of HRM decision-making in founder-led vs. professionally managed firms	Semi-structured interviews, thematic analysis	Assessing candid accounts of network-based decisions	P2, P5
Longitudinal tracking of HRM orientation change in organizations undergoing formalization	Repeated measures survey, case study	Identifying causal mechanisms vs. selection effects	P5, dynamic mechanisms
Sector-comparative analysis: technology vs. agriculture vs. public administration	Mixed methods within-country design	Controlling for firm-level vs. sector-level IEQ variation	P1, P4, P5
Generational cohort study of HRM norm preferences across age groups	Survey with cohort stratification	Separating age from cohort from period effects	P3, P5
Extension to comparable post-Soviet contexts: Central Asia, Eastern Partnership countries	Comparative cross-national design	Identifying South Caucasus-specific vs. generalizable framework elements	Framework generalisability

Note. IEQ = Institutional Environment Quality; NE = Network Embeddedness; PHC = Professional HRM Competence.

6.2. Methodological Guidance for Future Research

Future empirical studies testing the loyalty-performance framework face a specific methodological challenge that warrants explicit theoretical attention: measuring loyalty-logic versus performance-logic orientation in the absence of observable, objective HRM decision data. Self-reported survey measures of HRM practice are subject to well-documented social desirability bias, as practitioners are aware that network-based hiring is formally disapproved and may understate its prevalence. Future research should complement survey measures with scenario-based experimental designs, in which respondents are asked to make hypothetical hiring or promotion decisions under varying conditions of candidate network connections and formal

qualifications, thereby providing behavioral indicators of HRM orientation that are less susceptible to social desirability distortion.

Qualitative approaches, particularly semi-structured interviews and organizational ethnographies, remain essential for accessing the decision-making logics and relational dynamics that statistical measures cannot fully capture. The combination of qualitative depth and quantitative breadth in a convergent mixed-methods design offers the strongest methodological foundation for empirical investigation of the framework's propositions.

6.3. Conclusions

This paper has developed a conceptual framework of the loyalty-performance tension to understand how informal social networks shape HRM practices in the South Caucasus and, by extension, across a wide range of low-institutional-trust environments in post-Soviet and transitional economies. The framework integrates institutional theory, social capital scholarship, and comparative HRM research into a coherent four-determinant model that identifies the conditions under which loyalty logic or performance logic predominates in organizational people management decisions, specifies the mechanisms through which the loyalty-performance balance shifts over time, and advances five empirically testable propositions that establish a structured agenda for future research.

The framework's central theoretical claim that loyalty logic in HRM is not a cultural residue awaiting displacement through institutional modernization but a rational and functionally effective governance mechanism that persists because formal institutions do not yet provide equivalent guarantees of reliability, competence, and trustworthy conduct has important implications for how HRM reform is understood and designed in the region. Reform efforts that engage with the governance functions of informal networks, rather than treating them simply as obstacles to be removed through regulatory prescription, are more likely to produce substantive and durable changes in HRM practice than efforts premised on the assumption that institutional development will eventually make loyalty logic obsolete on its own.

The South Caucasus is not, in this analysis, simply a regional case study in the limitations of Western HRM theory. It is a theoretically productive site for examining, with unusual analytical clarity, a tension that operates wherever formal institutional capacity and informal network governance coexist, a condition that characterizes a substantial portion of the world's organizational environments. The loyalty-performance framework offers a conceptual tool for making that tension legible, for specifying its determinants and dynamics, and for deriving reform implications from those specifications that neither pure institutional theory nor pure social capital theory can generate alone.

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Technical Sciences

Экстракция биологически активных соединений из *Hypericum perforatum* L.

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Аннотация

Зверобой продырявленный (*Hypericum perforatum* L.) является ценным источником биологически активных фенольных соединений – флавоноидов (рутин, кверцетин, гиперозид), нафтодиантронов (гиперицин) и производных флороглюцина (гиперфорин), обладающих антиоксидантной, противомикробной и консервирующей активностью. Эффективность извлечения данных соединений из растительного сырья критически зависит от выбранного метода экстракции и его параметров. В настоящем исследовании проведён сравнительный анализ традиционных (мацерация, перколяция, отваривание, экстракция Соклетом, экстракция противотоком, водно-спиртовая экстракция с ферментацией) и современных (ультразвуковая, микроволновая, сверхкритическая флюидная, экстракция импульсным электрическим полем, гидродистилляция, Фитоника) методов экстракции применительно к сырью зверобоя. Экспериментально установлено, что для метода мацерации оптимальными параметрами являются: температура 50°C, продолжительность 24 часа, экстрагент – 70% этиловый спирт, соотношение сырьё: экстрагент 1:10. При данных условиях суммарное содержание фенольных соединений в экстракте из сухой травы зверобоя достигает 20,1 мг/г, а из образцов *in vitro* – 25,7 мг/г. Показано, что повышение концентрации этанола с 40% до 70% увеличивает выход фенольных соединений в 1,5-2,0 раза. Полученные результаты обосновывают выбор оптимального метода экстракции для максимального извлечения фенольных соединений из зверобоя с целью их использования в пищевой промышленности в качестве натуральных антиоксидантов и консервантов.

Ключевые слова: *Hypericum perforatum* L., зверобой продырявленный, экстракция фенольных соединений, мацерация, ультразвуковая экстракция, микроволновая экстракция, сверхкритическая флюидная экстракция, антиоксидантная активность, пищевая промышленность.

Введение

В пищевой промышленности экстракция является первым и критическим этапом получения натуральных функциональных ингредиентов – антиоксидантов, консервантов, ароматизаторов и биологически активных добавок. Несмотря на это, данному этапу нередко уделяется недостаточное внимание, хотя, до двух третей трудозатрат в аналитической практике приходится именно на пробоподготовку [1].

Развитие современных хроматографических и спектрометрических методов безусловно упрощает контроль качества пищевого сырья и готовых экстрактов, однако успех технологического процесса по-прежнему зависит от правильно выбранного метода экстракции, его параметров и особенностей растительной матрицы [2]. Ключевыми факторами, влияющими на эффективность извлечения биоактивных молекул, являются

структура растительной ткани, тип растворителя, температура, давление и продолжительность процесса [3].

За последние 50 лет наряду с традиционными методами в пищевой промышленности всё шире применяются нетрадиционные подходы. Эти методы характеризуются снижением потребления органических растворителей, сокращением времени экстракции, а также повышением выхода и селективности целевых компонентов [4]. К числу таких методов относятся ультразвуковая экстракция, микроволновая экстракция, экстракция сверхкритической углекислотой (CO₂), экстракция импульсным электрическим полем, ферментативная экстракция и др. [6]. Тем не менее традиционная экстракция Соклетом по-прежнему рассматривается как эталонный метод для сравнения эффективности вновь разработанных технологий [7].

Зверобой продырявленный (*Hypericum perforatum L.*) – растение, которое в пищевой промышленности и нутрициологии приобретает всё большее значение благодаря высокому содержанию фенольных соединений. В состав сырья входят флавоноиды (рутин, кверцетин, гиперозид), производные флороглюцина (гиперфорин), нафтодиантроны (гиперицин), а также дубильные вещества и фенолкарбоновые кислоты [8]. Эти соединения обладают выраженной антиоксидантной, противомикробной и консервирующей активностью, что делает зверобой перспективным сырьём для производства натуральных пищевых антиоксидантов, БАДов и фиточаёв [8].

Однако промышленное использование зверобоя в пищевых целях сталкивается с технологической проблемой: фенольные соединения локализованы внутриклеточно (в вакуолях и секреторных вместилищах) и частично связаны с клеточными стенками, что затрудняет их массоперенос в пищевые экстрагенты (вода, водно-спиртовые растворы, растительные масла). Кроме того, многие фенолы, особенно гипериперин и гиперфорин, термо- и светочувствительны: они разрушаются при нагревании выше 60–70 °С и окисляются на свету. Таким образом, для извлечения максимального количества фенольных соединений из зверобоя с целью их использования в пищевых продуктах необходим не произвольный, а научно обоснованный выбор метода экстракции, обеспечивающий: (1) высокую степень разрушения клеточных компартментов, (2) минимальную термическую и окислительную деградацию, (3) соответствие экстрагента требованиям пищевой безопасности.

Промышленное использование зверобоя в пищевой промышленности ограничено внутриклеточной локализацией фенольных соединений и их чувствительностью к воздействию температуры и света, что снижает эффективность их извлечения и сохранность. В связи с этим необходим выбор оптимального метода экстракции, обеспечивающего высокий выход фенольных соединений при минимальной деградации биоактивных компонентов. Целью исследования являлось обоснование рациональных условий экстракции фенольных соединений из зверобоя, пригодных для применения в пищевой промышленности.

Материалы и методы

Объектами исследования служили образцы травы зверобоя продырявленного, полученные двумя способами: Сухая трава, образцы *in vitro*.

Высушенное сырьё измельчали в лабораторной ножевой мельнице Pulverisette 11 (Fritsch, Германия) до состояния порошка.

В работе проведён сравнительный анализ традиционных и современных методов экстракции биологически активных веществ из растительного сырья. Экспериментальные исследования выполняли методом мацерации с использованием дистиллированной воды, 40%-ного и 70%-ного этанола при соотношении сырья и экстрагента 1:10. Экстрагирование проводили при температурах 30–70 °С в течение 24 часов. После фильтрования экстракты концентрировали на ротационном испарителе. Эффективность экстракции оценивали по

содержанию сухих веществ и суммарному содержанию фенольных соединений, определяемому спектрофотометрическим методом с реактивом Фолина–Чокальтеу. Результаты выражали в мг галловой кислоты на грамм экстракта (мг GAE/г) и представляли в виде среднего значения и стандартного отклонения ($M \pm SD$).

Результаты и обсуждение

Сравнительный анализ методов экстракции показал, что традиционные методы характеризуются простотой реализации, однако требуют значительных временных затрат и часто обеспечивают ограниченный выход целевых компонентов. Современные методы, включая ультразвуковую, микроволновую и сверхкритическую флюидную экстракцию, позволяют интенсифицировать процесс и повысить эффективность извлечения биологически активных веществ, однако связаны с использованием специализированного оборудования и более высокими эксплуатационными затратами. Далее в таблице 1 представлено влияние условий экстракции на содержание фенольных соединений в экстрактах зверобоя.

Таблица 1 – Влияние условий экстракции на содержание фенольных соединений в экстрактах зверобоя

Экстрагент	Температура, °C	Содержание фенольных соединений, мг GAE/г
Вода	30	$4,3 \pm 0,2^f$
40% этанол	30	$10,2 \pm 0,4^d$
70% этанол	30	$18,1 \pm 0,8^b$
Вода	50	$4,4 \pm 0,2^f$
40% этанол	50	$4,7 \pm 0,3^f$
70% этанол	50	$20,1 \pm 0,9^a$
70% этанол	60	$16,7 \pm 0,7^c$
70% этанол	70	$15,7 \pm 0,8^c$

Примечание: значения представлены как $M \pm SD$ ($n = 3$). Различные буквенные индексы указывают на статистически значимые различия между средними значениями ($p < 0,05$).

Как видно из таблицы 1, наибольший выход фенольных соединений обеспечивал 70%-ный этанол. Максимальное содержание фенольных соединений ($20,1 \pm 0,9$ мг GAE/г) было получено при температуре 50 °C. Повышение температуры до 60–70 °C сопровождалось снижением содержания фенольных соединений, что может быть связано с их частичной термической деградацией. Полученные результаты свидетельствуют о том, что концентрация экстрагента оказывает более выраженное влияние на эффективность экстракции, чем изменение температуры в исследованном диапазоне.

Для экспериментальной оценки была выбрана мацерационная экстракция как один из наиболее доступных и широко применяемых методов получения растительных экстрактов. Результаты исследования показали, что эффективность извлечения фенольных соединений из зверобоя существенно зависит от состава экстрагента и температуры процесса.

Во всех исследованных режимах наибольший выход фенольных соединений обеспечивал 70%-ный этанол. Максимальное содержание фенольных соединений было достигнуто при температуре 50 °C и составило 20,1 мг GAE/г для сухого растительного сырья и 25,7 мг GAE/г для образцов, полученных *in vitro*. При дальнейшем повышении температуры до 60–70 °C наблюдалось снижение содержания фенольных соединений, что может быть связано с их частичной термической деградацией.

Установлено, что образцы *in vitro* характеризовались более высоким выходом фенольных соединений по сравнению с традиционным растительным сырьём. Наиболее

выраженное различие наблюдалось при экстракции 70%-ным этанолом при 50 °С, где содержание фенольных соединений в образцах *in vitro* превышало аналогичный показатель сухого сырья на 27,9 %.

Таким образом, оптимальными условиями экстрагирования фенольных соединений из зверобоя методом мацерации являются использование 70%-ного этанола при температуре 50 °С, что обеспечивает максимальный выход целевых соединений и может быть рекомендовано для получения фенолсодержащих экстрактов пищевого назначения.

Заключение

Проведённый анализ методов экстракции растительного сырья показал, что выбор технологии определяется природой целевых соединений, требованиями к качеству экстракта и условиями производства. Среди традиционных методов мацерация сохраняет практическую значимость благодаря простоте реализации и возможности извлечения термочувствительных компонентов без интенсивного термического воздействия.

Установлено, что эффективность извлечения фенольных соединений из зверобоя продырявленного существенно зависит от температуры процесса и состава экстрагента. Наибольший выход фенольных соединений достигнут при использовании 70%-ного этанола при температуре 50 °С. В данных условиях содержание фенольных соединений составило 20,1 мг GAE/г для сухого растительного сырья и 25,7 мг GAE/г для образцов, полученных *in vitro*.

Показано, что сырьё, полученное *in vitro*, характеризуется более высоким выходом фенольных соединений по сравнению с традиционным растительным материалом, что свидетельствует о его перспективности в качестве источника биологически активных веществ.

Таким образом, оптимизированные параметры мацерационной экстракции обеспечивают эффективное извлечение фенольных соединений из зверобоя и могут быть использованы при разработке технологий получения натуральных экстрактов для пищевой промышленности, производства биологически активных добавок и функциональных продуктов питания.

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DÖVLƏT İNFORMASIYA SİSTEMLƏRİNİN TƏHSİL MÜƏSSİSƏLƏRİNDƏ İNTEQRASIYASI: PROBLEMLƏR VƏ HƏLL YOLLARI

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XÜLASƏ

XXI əsrdə informasiya-kommunikasiya texnologiyalarının sürətli inkişafı təhsil sistemində idarəetmə və təlim proseslərini dərinə dəyişmişdir. Dövlət informasiya sistemlərinin təhsil müəssisələrinə inteqrasiyası müasir təhsilin rəqəmsal əsasda qurulmasına, qərarların səmərəliliyinin artmasına və şəffaflığın təmininə xidmət edir. Məqalədə Azərbaycanın təhsil sektorunda dövlət informasiya sistemlərinin inkişafı, Ali Təhsil İnformasiya Sistemi (ATİS), Təhsil Mərkəzləşdirilmiş İnformasiya Sistemi (TMİS) kimi platformaların tətbiqi, bu inteqrasiyanın hüquqi və institusional əsasları, infrastruktur, texnologiya və insan resursları çətinlikləri təhlil edilir. Əldə edilmiş nəticələr göstərir ki, rəqəmsal strategiyalar və layihələrə baxmayaraq, informasiya sistemlərinin birgə işləməsi və informasiya təhlükəsizliyi sahəsində problemlər qalmaqdadır. Bu səbəbdən sənəddə vahid identifikasiya və autentifikasiya mexanizmlərinin qurulması, interoperabiliyə nail olunması, kadr hazırlığının gücləndirilməsi və kibertəhlükəsizlik tədbirlərinin təkmilləşdirilməsi üzrə təkliflər irəli sürülür.

Açar sözlər: *İnformasiya sistemləri, inteqrasiya, təhsil siyasəti, kibertəhlükəsizlik, ATİS, TMİS, e-hökumət*

ИНТЕГРАЦИЯ ГОСУДАРСТВЕННЫХ ИНФОРМАЦИОННЫХ СИСТЕМ В ОБРАЗОВАТЕЛЬНЫХ УЧРЕЖДЕНИЯХ: ПРОБЛЕМЫ И ПУТИ РЕШЕНИЯ РЕЗЮМЕ

В условиях стремительного развития информационно-коммуникационных технологий интеграция государственных информационных систем в образовательные учреждения становится ключевым направлением цифровой трансформации образования. В работе анализируются программы и нормативные акты Азербайджана, результаты внедрения централизованных систем управления данными (ATIS, TMIS), а также опыт их использования в университетах и школах. Обозначены барьеры, связанные с инфраструктурой, технологией и кадровым потенциалом, и показано, что отсутствие единого механизма идентификации, несовместимость систем и риски кибербезопасности затрудняют эффективный обмен информацией. Предложены рекомендации по созданию единой платформы для интеграции, повышению квалификации персонала, совершенствованию законодательной базы и усилению мер информационной безопасности.

Ключевые слова: *информационные системы, интеграция, образовательная политика, кибербезопасность, ATIS, TMIS, электронное правительство*

INTEGRATION OF STATE INFORMATION SYSTEMS IN EDUCATIONAL INSTITUTIONS: PROBLEMS AND SOLUTIONS SUMMARY

The rapid development of information and communication technologies has fundamentally transformed educational administration and learning. Integrating state information systems into educational institutions is essential for building a modern digital education system, increasing decision-making efficiency and ensuring transparency. This paper analyses the development of state information systems in Azerbaijan's education sector, particularly the implementation of platforms such as the Higher Education Information System (ATIS) and the Centralized Education Information System (TMIS). It assesses the legal and institutional framework supporting integration, examines infrastructure, technological and human resource challenges, and evaluates information security risks. The findings indicate that despite various digital strategies and projects, significant issues remain in system interoperability and data security. Consequently, the paper proposes recommendations for establishing unified identification and authentication mechanisms, achieving interoperability, strengthening workforce training and enhancing cybersecurity measures.

Keywords: *information systems, integration, educational policy, cybersecurity, ATIS, TMIS, e-government*

GİRİŞ

Mövzunun aktuallığı və məqsədi: İnformasiya cəmiyyətinin formalaşması təhsil sisteminin yenidən qurulmasını zəruri edən əsas proseslərdən biridir. Azərbaycan Respublikasında təhsil sisteminin informasiyalaşdırılması üzrə dövlət proqramında bildirilir ki, bilik iqtisadiyyatının formalaşdığı dövrdə informasiya-kommunikasiya texnologiyaları (İKT) ölkənin intellektual və elmi potensialının əsas göstəricilərindəndir. Proqramın məqsədi ümumtəhsil məktəblərinin və ali məktəblərin İKT infrastrukturunu gücləndirməklə təhsilin idarə edilməsinin və monitorinqinin effektivliyini artırmaqdır. Eyni sənəddə qeyd olunur ki, Azərbaycanda 2005–2007-ci illərdə ümumtəhsil məktəblərinin İKT ilə təminatı proqramı həyata keçirilmiş və nəticədə məktəblərin 82 faizi kompüter avadanlığı ilə təmin olunmuşdur.

Rəqəmsal transformasiya ərəfəsində dövlət informasiya sistemlərinin təhsil müəssisələrində inteqrasiyası iki məqamı ön plana çıxarır: (1) məlumatların real vaxt rejimində toplanması, emalı və qərarların qəbulu üçün vahid infrastruktur qurmaq; (2) tədris prosesini rəqəmsallaşdıraraq müəllim və tələbələrə yeni tədris resurslarına çıxış imkanını artırmaq. Mövcud vəziyyət göstərir ki, təhsil sektorunda müxtəlif informasiya sistemləri fəaliyyət göstərsə də, onların bir-biri ilə tam inteqrasiyası təmin edilmədiyindən həm idarəetmədə, həm də xidmət göstərilməsində informasiya boşluqları yaranır. Bu məqalənin məqsədi Azərbaycanda dövlət informasiya sistemlərinin təhsil müəssisələrində inteqrasiyasının mahiyyətini izah etmək, mövcud problemləri qiymətləndirmək və həll yollarını təklif etməkdir.

Dövlət informasiya sistemlərinin təhsildə rolu: Dövlət informasiya sistemləri – Elektron Hökumət İnformasiya Sistemi (EHİS), Ali Təhsil İnformasiya Sistemi (ATİS), Ümumi Təhsil İnformasiya Sistemi (UTİS), Təhsil Mərkəzləşdirilmiş İnformasiya Sistemi (TMİS) və portal.edu.az kimi platformalar – təhsil müəssisələrinə dair məlumatların toplanması, saxlanması və istifadəçilərə çatdırılması üçün yaradılmışdır. Azərbaycan Prezidentinin 2004-cü il 21 avqust sərəncamı ilə təsdiq edilən ümumtəhsil məktəblərinin İKT ilə təminatı proqramı və onun ardınca 2008–2012-ci illər üzrə təhsil sisteminin informasiyalaşdırılması proqramı vahid elektron təhsil məkanının formalaşdırılmasını məqsəd qoymuşdur.

Ali Təhsil İnformasiya Sistemi (ATİS) universitetlərdə tələbə və müəllim məlumatlarının vahid platformada idarə olunmasını nəzərdə tutur. Neuron Technologies şirkətinin rəhbəri İsmayıl Ələkbərovun sözlərinə görə, ATİS yüz minlərlə tələbənin və müəllimlərin məlumatlarını real vaxt

rejimində emal edə bilən mürəkkəb platformadır və bir neçə universitet pilot olaraq bu sistemə qoşulduqdan sonra əhatə dairəsinin genişləndirilməsi planlaşdırılır. Hər bir təhsil müəssisəsinə ayrıca interfeys və giriş məlumatları verilir; məqsəd bütün təhsil məlumatlarının kağız deyil, elektron formada aparılmasıdır.

2023-cü ildə Elm və Təhsil Nazirliyinin informasiya sistemlərinə giriş bulud əsaslı SiMA rəqəmsal imzası vasitəsilə təşkil edildi. AzərTAc xəbər agentliyinin məlumatında bildirilir ki, yeni nəsil rəqəmsal imza vasitəsilə “Ali və orta ixtisas təhsili” altsistemlərinə giriş prosesi sadələşdirilmiş və sistemə etibarlı giriş təmin edilmişdir.

Mövzunun tədqiqat obyektı və predmeti: Tədqiqatın obyektı Azərbaycan Respublikasında təhsil müəssisələrinə dair məlumatların idarə edilməsi üçün istifadə olunan dövlət informasiya sistemləridir. Predmet isə bu sistemlərin təhsil müəssisələrinin daxili informasiya sistemləri ilə inteqrasiyası, inteqrasiyanın hüquqi və texniki əsasları, qarşıya çıxan problemlər (məlumat təhlükəsizliyi, infrastruktura və insan resurslarının yetərsizliyi, sistemlərarası interoperabilitiyin olmaması) və onların həll yollarıdır.

Əsas hissə

Dövlət informasiya sistemlərinin təhsil sektoruna inteqrasiyası prosesləri

İnformasiya sistemlərinin inteqrasiyası müxtəlif platformalarda toplanan məlumatların vahid sistemdə birləşdirilməsi və qarşılıqlı istifadəsinə yönəlib. Beynəlxalq elmi ədəbiyyatda inteqrasiya ilə interoperabilitiya arasındakı fərq qeyd edilir: inteqrasiyanın məqsədi müxtəlif sistemlərdən məlumatların toplanması və mərkəzi sistemə təqdim edilməsi olduğu halda, interoperabilitiya sistemlərin bir-biri ilə fasiləsiz ünsiyyəti və funksionallığın paylaşılmasını təmin edir. Jakimoski qeyd edir ki, təhsil sektorunda sistemlərin interoperabilitiyinə nail olunmaması departamentlər və təhsil müəssisələri arasında məlumat mübadiləsinə çətinləşdirir; buna görə də məktəb interoperabilitiyi çərçivəsi (SIF) və elektron idarəetmə məlumat sistemi kimi standartlar tətbiq edilir [4].

Azərbaycan təhsil sistemində inteqrasiya təşəbbüsləri

Azərbaycanın təhsil siyasətində ilk genişmiqyaslı inteqrasiya addımı ümumtəhsil məktəblərinin İKT ilə təmin edilməsi proqramı ilə atıldı. 2005–2007-ci illərdə 4562 ümumtəhsil məktəbinin 82 faizi kompüterlə təmin olundu; 2007-ci ilin sonuna hər 29 şagirdə bir kompüter düşürdü [2]. Sonrakı mərhələdə Təhsil Nazirliyi “Xalq Kompüterı” layihəsini həyata keçirdi. Bu layihə çərçivəsində müəllimlərə, ali məktəb müəllim və tələbələrinə güzəştli şərtlərlə kompüter və lisenziyalı proqram təminatı verildi ki, bu da təhsil sisteminin yeni elektron bazaya keçidini dəstəkləmək məqsədi daşıyırdı [6, s.22].

2010-cu il Azərbaycanda “Təhsil sahəsi üzrə İKT ili” elan edildi. Bu il ərzində konfranslar, seminarlar və müxtəlif stimullaşdırıcı tədbirlər təşkil olundu, məktəblər elektron lövhələrlə təmin edildi və müəllimlərin İKT bacarıqlarının artırılması prioritet seçildi. İKT vasitələrinin tədris prosesinə daxil edilməsi dərs modelini dəyişərək “müəllim–tələbə–dərslik” strukturuna kompüter komponentini əlavə etdi və fərdi tədris proqramlarının tərtibinə imkan yaratdı.

Bu ilkin mərhələlərdən sonra təhsil sektorunda daha iri sistemlərin yaradılması başladı. ATİS universitet səviyyəsində idarəetmə məlumatlarını mərkəzləşdirmək üçün yaradıldı və hazırda ölkənin universitetləri tədricən bu platformaya inteqrasiya olunur. Ümumi təhsil müəssisələri üçün UTİS, peşə təhsili üçün isə müvafiq alt sistemlər fəaliyyət göstərir [1]. 2026-cı ildə Nazirlər Kabineti təhsil haqqında dövlət sənədlərinin tam elektron formatda verilməsini təsdiqlədi. Qərara əsasən, diplomlar və sertifikatlar TMİS üzərindən elektron sənəd kimi formalaşdırılacaq, sənədlərə ştrix-kod əlavə ediləcək və məlumatlar EHİS vasitəsilə təhlükəsiz şəkildə təqdim olunacaq. Bu addım təhsil sənədlərinin sürətlə və şəffaf şəkildə verilməsini təmin etməklə yanaşı, müxtəlif informasiya sistemləri arasında inteqrasiya mexanizminin vacibliyini göstərir [9].

Təhsil müəssisələrində informasiya sistemlərinin tətbiq təcrübəsi

Müasir təhsil müəssisələri yalnız kargüzarlıq sistemləri deyil, tədris prosesini idarə edən və təhsil resurslarının paylaşılmasını təmin edən informasiya sistemlərindən də istifadə edirlər. Məsələn, portal.edu.az vasitəsilə abituriyentlərin elektron sənəd qəbulu və digər xidmətlər göstərilir. Lakin Osman Gündüzün xəbər portallarına istinadən bildirdiyi kimi, magistratura səviyyəsinə sənəd qəbulu zamanı namizədlər həm portal.edu.az-da, həm də universitetin öz sistemində ayrı-ayrılıqda qeydiyyatdan keçməli və sonda kağız sənədləri təqdim etməli olurlar [3]. Ekspertin fikrincə, rəqəmsal transformasiyanın məqsədi prosesləri sadələşdirmək olsa da, inteqrasiyanın olmaması nəticəsində iki və ya üç mərhələli qeydiyyat mexanizmi formalaşmışdır. Bu fakt təhsil müəssisələrinin informasiya sistemlərindən istifadə təcrübəsində vahid platformaya ehtiyacın olduğunu göstərir.

Digər təcrübə misalı TMİS-in tətbiqidir. 2026-cı ildən etibarən təhsil haqqında bütün sənədlər TMİS üzərindən elektron formada yaradılaraq EHS-dəki şəxsi kabinetlərə göndəriləcək; məzunlar istənilən vaxt sənədlərinə çıxış əldə edə biləcəklər [9]. Bu, diplom və attestatların doğruluğunun operativ yoxlanılmasına və kağız dövriyyəsinin ləğvinə şərait yaradır.

İnformasiya təhlükəsizliyi ilə bağlı qarşıya çıxan problemlər

Təhsil müəssisələrinin elektron sistemlərinin genişlənməsi kibertəhlükəsizliyin əhəmiyyətini artırır. AMEA İnformasiya Texnologiyaları İnstitutunda keçirilən seminarla bildirildiyi kimi, elektron təhsil platformalarına yönəlik təhlükələrə saytlarası skript (XSS), virus və trojanlar vasitəsilə uzaqdan inyeksiya, URL ünvanına SQL injeksiyası və veb-sayt sessiya identifikasiyasının təxmin edilməsindən istifadə edərək parolların sındırılması daxildir. Araşdırıcı Rəna Məlikova vurğulamışdır ki, təhsil məlumatlarının mühafizəsi üçün təşkilati tədbirlər, proqram təminatının qorunması və avadanlıq səviyyəsində müdafiə mexanizmləri zəruridir; giriş subyektlərinin identifikasiyası və autentifikasiyası, məlumatların kriptografik və antivirus mühafizəsi, rabitə kanallarının qorunması bu tədbirlərə daxildir [5].

İnformasiya texnologiyalarının sürətli inkişafı məlumatların daşınmasını artırdığı üçün məlumatların gizliliyinin qorunması çətinləşir və təhlükələrə qarşı effektiv kriptografik metodlara ehtiyac yaranır [8].

İnformasiya sistemlərinin inteqrasiyasında təhlükəsizlik probleminin başqa aspekti onların həssaslığıdır. Məlumat bazaları bir-biri ilə əlaqələndirildikdə, bir sistemdəki zəiflik digər sistemi də risk altında qoya bilər. Ekspertlər qeyd edirlər ki, müxtəlif dövlət qurumlarında olan məlumatlar eyni şəxslə bağlıdırsa, kağız və ya elektron formada vətəndaşdan yenidən tələb edilməsi yolverilməzdir; bunun əvəzinə inteqrasiya olunmuş və təhlükəsiz məlumat mübadiləsi mexanizmləri qurulmalıdır [3].

İnfrastruktur, texnologiya və insan resursları ilə bağlı çətinliklər

İnformasiya sistemlərinin effektiv işləməsi üçün müvafiq texniki baza, dayanıqlı telekommunikasiya infrastrukturunu və peşəkar kadrlar lazımdır. Təhsil sisteminin informasiyalaşdırılması dövlət proqramında 2012-ci ilədək ölkənin ali məktəblərinin hamısının, texniki-peşə müəssisələrinin isə 42 faizinin kompüterlə təmin olunduğu göstərilərsə də, bölgələrdə internet bağlantısının keyfiyyəti və avadanlığın yenilənmə dərəcəsi qeyri-bərabərdir [2].

İnsan resursları məsələsinə gəlincə, müəllim və inzibati heyətin İKT bacarıqları hələ də kifayət qədər deyil. 2010-cu ildə Təhsil Nazirliyi tərəfindən "Təhsil sahəsi üzrə İKT ili" elan edildikdə müəllimlərin təlimləndirilməsi prioritet seçilmiş və minlərlə müəllim hazırlıq kurslarına cəlb olunmuşdur. Lakin rəqəmsal sistemlərin daim yenilənməsi səbəbindən davamlı təlim proqramları və yeni mütəxəssislərin cəlb olunmasına ehtiyac qalır. İnformasiya təhlükəsizliyinin müasir problemləri üzrə tədqiqatda qeyd olunduğu kimi, kibertəhlükəsizlik mütəxəssislərinə tələbat artmaqda, amma işçi bazarında bu kadrlar çatışmır və təhsil müəssisələrinin mühafizəsini çətinləşdirir.

Təhsil müəssisələrində təhlükəsizlik tədbirlərinin təkmilləşdirilməsi istiqamətləri

Mövcud problemlərin həlli üçün bir neçə istiqamət təklif olunur. Birincisi, vahid identifikasiya və autentifikasiya mexanizmlərinin qurulması vacibdir. SİMA rəqəmsal imzasının ATİS və TMİS kimi sistemlərə inteqrasiyası istifadəçilərin identifikasiyasını sadələşdirir və təhlükəsizliyi artırır. Bu mexanizm digər təhsil alt sistemlərinə də tətbiq olunmalı və bütün təhsil müəssisələri üçün vahid giriş mühiti yaradılmalıdır [7].

İkincisi, interoperabiliyə nail olunması üçün sistemlərin açıq standartlar əsasında qurulması və məlumat mübadiləsinin vahid protokollarla həyata keçirilməsi zəruridir. Jakimoskinin tədqiqatında qeyd olunduğu kimi, xidmət-yönümlü memarlıq (SOA) və XML standartları üzərində qurulan School Interoperability Framework müxtəlif təhsil sistemləri arasında məlumat paylaşımını təmin edir. Azərbaycanın təhsil informasiya sistemləri də bu tip strukturlar əsasında inkişaf etdirilərək EHİS ilə tam inteqrasiya olunmalıdır [4].

Üçüncüsü, kibertəhlükəsizliyin gücləndirilməsi məqsədilə təhlükə analizi və risk idarəetmə prosedurlarının tətbiqi vacibdir. Rəna Məlikovanın araşdırmasında vurğulanan XSS, SQL inyeksiya və sessiya identifikasiyası kimi hücum növlərinə qarşı proqram təminatı səviyyəsində filtrasiya, şifrləmə, iki faktorlu autentifikasiya və istifadəçi sessiyalarının təhlükəsiz idarə edilməsi kimi tədbirlər görülməlidir. Eyni zamanda, təhsil müəssisələrində kibertəhlükəsizlik üzrə mütəmadi auditlər aparılmalı, müəllim və tələbələr üçün maarifləndirici təlimlər təşkil edilməlidir [5].

Nəhayət, infrastrukturun yenilənməsi və kadr hazırlığı sahəsində dövlət və özəl sektorun iştirakı ilə investisiya proqramları həyata keçirilməlidir. Bölgələrdə genişzolaqlı internet şəbəkəsinin inkişafı, təhsil müəssisələrinin server və bulud resurslarına çıxışının təmin olunması, rəqəmsal resursların yaratdığı hüquqi və etik məsələlərə dair tədqiqatların aparılması da vacibdir [5].

Nəticə

Tədqiqat göstərir ki, Azərbaycan təhsil sistemində dövlət informasiya sistemlərinin inteqrasiyası prosesi davamlı olaraq inkişaf etsə də, hələ də həll olunmamış problemlər mövcuddur. 2005-ci ildən başlayaraq İKT ilə təminat proqramları və “Xalq Kompüter” layihəsi təhsil müəssisələrinin texniki bazasını xeyli yaxşılaşdırmış, ATİS və TMİS kimi platformaların tətbiqi isə məlumatların mərkəzləşdirilməsini təmin etmişdir. 2026-cı il qərarı ilə diplom və sertifikatların elektron formada verilməsi rəqəmsal idarəetmənin yeni mərhələsini başlatmışdır. Lakin inteqrasiya və interoperabiliyin tam təmin olunmaması nəticəsində paralel qeydiyyat prosesləri, məlumat təkrarı və istifadəçilər üçün əlavə bürokratiya yaranır.

Praktiki tövsiyələrə gəldikdə, təhsil sektorunda vahid identifikasiya və autentifikasiya mexanizmlərinin tətbiqi, məlumat mübadiləsi üçün açıq standartların seçilməsi və təhlükəsizlik auditlərinin həyata keçirilməsi vacibdir. Təhsil müəssisələrində kibertəhlükəsizlik mədəniyyətinin formalaşdırılması məqsədilə müəllim və tələbələr üçün təlimlər təşkil olunmalı, informasiya sistemləri üzrə kadrların hazırlığına investisiya qoyulmalıdır. İnfrastrukturun yenilənməsi, genişzolaqlı internetə çıxışın təmin edilməsi və informasiya sistemlərinin EHİS-lə inteqrasiyasının tamamlanması da əsas prioritetlərdəndir.

Gələcək tədqiqatlar təhsil informasiya sistemlərində süni intellekt və böyük məlumat analitikasının tətbiqi, bulud texnologiyalarının effektivliyi, təhsil sənədlərinin transsərhəd tanınması üçün blokçeyn həlləri və məlumatların məxfiliyinin qorunması kimi mövzulara yönəldilə bilər. Bu istiqamətlər həm nəzəri, həm də tətbiqi baxımdan vacibdir və təhsil müəssisələrində rəqəmsal transformasiyanın dərinləşdirilməsinə töhfə verəcəkdir.

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TƏHLİLİN VƏ ANALİZİN İNFORMASIYA SİSTEMLƏRİNİN İNTEQRASIYASINDA TƏSİRİNİN QIYMƏTLƏNDİRİLMƏSİ

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XÜLASƏ

Müasir rəqəmsal iqtisadiyyat şəraitində informasiya sistemlərinin inteqrasiyası müəssisələrin rəqabət qabiliyyətinin artırılması, biznes proseslərinin optimallaşdırılması və idarəetmə qərarlarının effektivliyinin yüksəldilməsi baxımından xüsusi əhəmiyyət kəsb edir. Tədqiqatın aktuallığı müxtəlif informasiya sistemlərinin vahid mühitdə inteqrasiyası zamanı təhlil və analiz proseslərinin həlledici rol oynaması ilə əlaqədardır. Bu baxımdan məqalənin məqsədi təhlil və analizin informasiya sistemlərinin inteqrasiyasına təsirini araşdırmaq, onların inteqrasiya layihələrinin uğurlu icrasına və səmərəliliyinə təsirini qiymətləndirməkdir. Tədqiqat zamanı sistemli yanaşma, müqayisəli təhlil və elmi ədəbiyyatın araşdırılması metodlarından istifadə edilmişdir.

Araşdırmanın nəticələri göstərir ki, keyfiyyətli təhlil və analiz inteqrasiya prosesində məlumat axınlarının düzgün müəyyənəşdirilməsinə, texniki və təşkilati risklərin azaldılmasına, resurslardan səmərəli istifadəyə və inteqrasiya xərclərinin optimallaşdırılmasına şərait yaradır. Eləcə də düzgün aparılmış analiz müəssisənin tələblərinə uyğun inteqrasiya modelinin seçilməsinə və informasiya sistemlərinin qarşılıqlı fəaliyyətinin təmin edilməsinə imkan verir.

Nəticə etibarilə müəyyən edilmişdir ki, təhlil və analiz informasiya sistemlərinin inteqrasiyasının əsas uğur amillərindən biri olmaqla rəqəmsal transformasiya proseslərinin effektiv həyata keçirilməsinə, müəssisələrin idarəetmə qabiliyyətinin gücləndirilməsinə və ümumi fəaliyyət səmərəliliyinin artırılmasına mühüm töhfə verir.

Açar sözlər: *informasiya sistemi, sistem inteqrasiyası, informasiya təhlili, biznes analizi, rəqəmsal transformasiya*

ASSESSMENT OF THE IMPACT OF ANALYSIS AND EVALUATION ON INFORMATION SYSTEMS INTEGRATION

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SUMMARY

In the context of the modern digital economy, the integration of information systems plays a significant role in enhancing the competitiveness of enterprises, optimizing business processes, and improving the effectiveness of managerial decision-making. The relevance of this study is associated with the crucial role of analysis and evaluation processes in the integration of various information systems within a unified environment. Accordingly, the aim of the article is to investigate the impact of analysis and evaluation on information systems integration and to assess their influence on the successful implementation and efficiency of integration projects.

The research employs a systematic approach, comparative analysis, and a review of scientific literature as its primary research methods. The findings indicate that high-quality analysis and

evaluation contribute to the accurate identification of information flows during the integration process, reduction of technical and organizational risks, efficient utilization of resources, and optimization of integration costs. Furthermore, properly conducted analysis enables the selection of an integration model that meets organizational requirements and ensures interoperability among information systems.

The study concludes that analysis and evaluation are among the key success factors of information systems integration. They significantly contribute to the effective implementation of digital transformation processes, the strengthening of organizational management capabilities, and the overall improvement of operational efficiency.

Keywords: *information systems, systems integration, information analysis, business analysis, digital transformation*

Giriş

İnformasiya texnologiyalarının sürətli inkişafı müəssisələrin fəaliyyətinin təşkilində yeni yanaşmaların formalaşmasına səbəb olmuşdur. Müasir təşkilatlar öz fəaliyyətlərini həyata keçirmək üçün ERP, CRM, SCM, HRM və digər informasiya sistemlərindən geniş istifadə edirlər. Bu sistemlər müxtəlif funksiyaları yerinə yetirsə də, onların ayrı-ayrılıqda fəaliyyət göstərməsi məlumatların təkrarlanmasına, idarəetmə proseslərində gecikmələrə və resurslardan qeyri-səmərəli istifadəyə səbəb ola bilər.

Bu problemlərin həlli üçün informasiya sistemlərinin inteqrasiyası mühüm əhəmiyyət kəsb edir. Sistem inteqrasiyası müxtəlif informasiya sistemlərinin vahid informasiya mühitində əlaqələndirilməsi və onların qarşılıqlı fəaliyyətinin təmin olunması prosesidir. İnteqrasiyanın effektiv həyata keçirilməsi üçün mövcud sistemlərin funksional imkanlarının, məlumat strukturlarının və biznes proseslərinin ətraflı təhlili tələb olunur.

Təhlil və analiz inteqrasiya layihələrinin planlaşdırılması və həyata keçirilməsinin əsasını təşkil edir. Bu mərhələlərdə mövcud vəziyyət qiymətləndirilir, problemlər müəyyən edilir və inteqrasiya üçün optimal həllər hazırlanır. Buna görə də təhlilin və analizin informasiya sistemlərinin inteqrasiyasında rolunun öyrənilməsi aktual elmi və praktiki əhəmiyyət daşıyır.

İnformasiya sistemlərinin inteqrasiyasının nəzəri əsasları

İnformasiya sistemlərinin inteqrasiyası müəssisədə mövcud olan müxtəlif proqram və texnoloji platformaların qarşılıqlı əlaqəsini təmin edən prosesdir. Bu proses nəticəsində müxtəlif sistemlər arasında məlumat mübadiləsi avtomatlaşdırılır və vahid informasiya məkanı formalaşdırılır.

İnteqrasiya əsasən aşağıdakı səviyyələr üzrə təsnif edilir:

- Verilənlər səviyyəsində inteqrasiya;
- Tətbiqlər səviyyəsində inteqrasiya;
- Biznes prosesləri səviyyəsində inteqrasiya;
- Xidmətyönlü arxitektura (SOA) əsasında inteqrasiya;
- Mikroservis əsaslı inteqrasiya.

Müəssisələrdə inteqrasiya olunmuş informasiya sistemləri məlumatların operativ emalına, idarəetmə proseslərinin şəffaflığına və qərarların qəbul edilməsində etibarlı informasiya təminatına şərait yaradır.

Təhlil və analizin mahiyyəti

Təhlil mövcud informasiya sistemlərinin, biznes proseslərinin və məlumat axınlarının öyrənilməsi prosesidir. Analiz isə əldə edilmiş məlumatların sistemləşdirilməsi, qiymətləndirilməsi və qərarların hazırlanmasına yönəlmiş fəaliyyətdir.

İnteqrasiya layihələrində təhlil və analiz aşağıdakı istiqamətləri əhatə edir:

- Biznes proseslərinin təhlili müəssisədə həyata keçirilən əməliyyatların ardıcılığını və qarşılıqlı əlaqələrini müəyyən etməyə imkan verir. Bu zaman məlumatların yaranması, emalı və ötürülməsi mərhələləri araşdırılır.
- Məlumat axınlarının təhlili sistemlər arasında ötürülən informasiyanın mənbələrini, istiqamətlərini və strukturunu müəyyən edir. Bu mərhələ inteqrasiya zamanı yaranan məlumat uyğunsuzluqlarının qarşısının alınmasına kömək edir.
- Texniki analiz istifadə olunan proqram platformalarının, verilənlər bazalarının və kommunikasiya protokollarının uyğunluğunu qiymətləndirməyə imkan verir. Burada API-lər, məlumat mübadiləsi standartları və inteqrasiya mexanizmləri araşdırılır.
- Risk analizi inteqrasiya zamanı yarana biləcək texniki, iqtisadi və təşkilati problemlərin müəyyən edilməsinə xidmət edir. Risklərin vaxtında aşkarlanması layihənin uğur ehtimalını artırır.

Təhlilin informasiya sistemlərinin inteqrasiyasına təsiri

Təhlil və analiz inteqrasiya prosesinin bütün mərhələlərinə təsir göstərir. Aparılmış araşdırmalar göstərir ki, inteqrasiya layihələrinin uğursuzluğunun əsas səbəblərindən biri ilkin təhlilin qeyri-kafi aparılmasıdır. Təhlilin əsas təsirləri aşağıdakılardır:

- Təhlil nəticəsində məlumatların təkrarlanması, natamamlığı və uyğunsuzluğu müəyyən edilir. Bu problemlərin aradan qaldırılması inteqrasiya olunmuş sistemdə daha etibarlı məlumat bazasının formalaşmasına imkan verir.
- Ətraflı təhlil müəssisədə mövcud texniki və insan resurslarının optimal istifadəsini təmin edir. Bu isə inteqrasiya layihəsinin dəyərinin azalmasına səbəb olur.
- Təhlil mərhələsində potensial risklərin müəyyən olunması onların idarə edilməsini asanlaşdırır və layihənin uğurla tamamlanma ehtimalını artırır.
- Inteqrasiya nəticəsində vahid informasiya məkanının formalaşması rəhbərliyə operativ və əsaslandırılmış qərarlar qəbul etməyə imkan verir.

İnformasiya sistemlərinin inteqrasiyasında müasir texnologiyaların rolu

Son illərdə rəqəmsal transformasiya prosesləri inteqrasiya texnologiyalarının inkişafına təkan vermişdir. Müasir müəssisələr aşağıdakı texnologiyalardan istifadə etməklə inteqrasiya proseslərini həyata keçirirlər:

- Bulud texnologiyaları (Cloud Computing);
- Böyük verilənlər texnologiyaları (Big Data);
- Süni intellekt sistemləri (Artificial Intelligence);
- Mikroservis arxitekturası;
- REST və GraphQL API texnologiyaları;
- Xidmətyönümlü arxitektura (SOA).

Xüsusilə süni intellekt texnologiyalarının tətbiqi məlumatların avtomatik təhlilinə, anomaliyaların aşkarlanmasına və proqnozlaşdırıcı analitikanın həyata keçirilməsinə imkan verir.

Təhlilin effektivliyinin qiymətləndirilməsi metodları

Müasir müəssisələrdə həyata keçirilən təhlil proseslərinin keyfiyyətinin müəyyən edilməsi qəbul edilən qərarların düzgünlüyünü, resurslardan istifadənin səmərəliliyini və layihələrin uğur səviyyəsini qiymətləndirməyə imkan verir. Bu məqsədlə müxtəlif qiymətləndirmə metodlarından istifadə olunur. Ən geniş yayılmış yanaşmalardan biri əsas performans göstəricilərinin (KPI) tətbiqidir. Bu metod vasitəsilə təhlilin nəticələri əvvəlcədən müəyyən edilmiş göstəricilər əsasında ölçülür və qiymətləndirilir. Məsələn, tələblərin düzgün müəyyənləşdirilməsi səviyyəsi, aşkarlanan problemlərin sayı, layihənin icra müddəti və istifadəçi məmnunluğu kimi göstəricilər təhlilin effektivliyinin müəyyən edilməsində istifadə olunur.

Təhlilin səmərəliliyinin qiymətləndirilməsində xərc-fayda təhlili də mühüm yer tutur. Bu yanaşma təhlil prosesinə sərf olunan maliyyə və vaxt resurslarının əldə edilən nəticələrlə müqayisəsinə əsaslanır. Əgər təhlil nəticəsində layihə riskləri azalır, inteqrasiya xərcləri optimallaşdırılır və biznes proseslərinin məhsuldarlığı artırsa, həmin təhlil effektiv hesab olunur. Bununla yanaşı, SWOT analizi vasitəsilə təhlilin güclü və zəif tərəfləri, eləcə də mövcud imkanlar və potensial təhlükələr müəyyən edilir.

Müqayisəli təhlil metodunda təşkilatın təhlil nəticələri sənaye standartları, rəqib müəssisələrin göstəriciləri və ya əvvəlki dövrlərin nəticələri ilə müqayisə edilir. Belə müqayisələr təhlilin keyfiyyət səviyyəsini müəyyən etməyə və təkmilləşdirmə istiqamətlərini aşkar etməyə imkan verir. Eləcə də ekspert qiymətləndirməsi metodu vasitəsilə mütəxəssislərin rəy və təcrübələrindən istifadə olunaraq aparılmış təhlilin dəqiqliyi, məlumatların tamlığı və təqdim edilən həllərin məqsədəuyğunluğu qiymətləndirilir.

Balanslaşdırılmış göstəricilər sistemində maliyyə nəticələri, müştəri məmnunluğu, daxili biznes prosesləri və innovasiya potensialı kimi müxtəlif istiqamətlər üzrə təhlilin nəticələrini qiymətləndirməyə imkan verir. Bundan əlavə, risk analizi metodları vasitəsilə təhlilin təşkilat üçün yarada biləcəyi və ya qarşısını ala biləcəyi risklər müəyyən edilir. Risklərin azalması və qeyri-müəyyənliyin minimuma endirilməsi təhlilin uğurlu aparıldığını göstərən mühüm göstəricilərdən hesab olunur.

Nəticə

Aparılmış tədqiqat göstərir ki, təhlil və analiz informasiya sistemlərinin inteqrasiyasında strateji əhəmiyyətə malikdir. Düzgün aparılmış təhlil biznes proseslərinin optimallaşdırılmasına, məlumat keyfiyyətinin yüksəldilməsinə və inteqrasiya risklərinin azaldılmasına imkan verir. Analiz nəticəsində əldə olunan məlumatlar inteqrasiya layihələrinin daha səmərəli planlaşdırılmasını və idarə olunmasını təmin edir.

Rəqəmsal transformasiya şəraitində müəssisələrin rəqabət qabiliyyətinin artırılması üçün informasiya sistemlərinin inteqrasiyasında müasir təhlil və analiz metodlarının tətbiqi vacib şərt hesab olunur. Gələcək tədqiqatlarda süni intellekt əsaslı analitik sistemlərin inteqrasiya layihələrinin effektivliyinə təsirinə daha dərinəndən araşdırılması məqsədəuyğun hesab edilir.

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Comparative Assessment of Bioactive Compounds and Elemental Composition (Minerals and Toxic Elements) in Extract-Enriched Yogurt

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Abstract

This study aimed to compare the content of bioactive compounds and elemental composition in control yogurt and yogurt enriched with sweet clover (*Melilotus officinalis*) extract. The enriched yogurt showed a higher total polyphenol content ($1.34 \pm 0.05\%$ vs. $1.28 \pm 0.05\%$) and slightly lower flavonoid content ($0.53 \pm 0.02\%$ vs. $0.59 \pm 0.03\%$) compared with the control sample. Both samples contained detectable levels of B-group vitamins and vitamin C, with minor differences between the formulations. The yogurt with sweet clover extract was characterized by slightly increased concentrations of calcium Ca, potassium K, magnesium Mg and phosphorus P, while levels of zinc Zn and iron Fe remained within a comparable range to the control. In all samples, toxic elements (lead Pb, cadmium Cd, arsenic As, mercury Hg) and cesium-137 were not detected, and activity of potassium-40 remained within regulatory limits. The results indicate that enrichment of yogurt with sweet clover extract improves its profile of bioactive compounds and minerals without compromising safety indicators, supporting its potential as a functional dairy product.

Keywords—bioactive compounds, functional yogurt, mineral composition, sweet clover.

INTRODUCTION

In recent years, particular attention has been paid to the use of plant-derived bioactive compounds in the development of functional food products. Polyphenols and flavonoids occurring in plant raw materials exhibit high antioxidant activity, help to reduce oxidative stress in the human body and may contribute to the prevention of chronic diseases. Among medicinal plants, *Melilotus officinalis* (sweet clover) occupies an important place due to its content of coumarins, phenolic compounds, flavonoids and mineral elements, which together determine its high biological activity. The antioxidant and pharmacological properties of sweet clover extracts have been confirmed in a number of experimental studies, including investigations of anti-inflammatory, cardioprotective and wound-healing effects [1,2,3].

Polyphenols and flavonoids strengthen cellular defence mechanisms and reduce the damaging action of free radicals, which explains the growing interest in their incorporation into

functional food matrices. At the same time, the process of obtaining extracts from plant material substantially affects the composition and yield of these bioactive substances, since extraction conditions such as solvent type, temperature and duration can change their concentration and stability. Therefore, the technological step of extraction plays a decisive role in shaping the final quality of plant-based ingredients intended for food enrichment [2,4].

Currently, the enrichment of dairy products with plant extracts is considered one of the most promising directions in functional food production. Fermented milk products such as yogurt provide a favourable matrix that can improve the stability and bioavailability of bioactive compounds, while maintaining the inherent nutritional advantages of milk, including high-quality protein and calcium. Previous studies have shown that the addition of various plant extracts to yogurt can enhance its antioxidant activity, modify its physicochemical properties and increase consumer appeal. Moreover, the use of local plant raw materials from regions such as Northern Kazakhstan is of practical importance, as these plants are rich in biologically active substances and can serve as a basis for developing new value-added functional products [5,6].

In this context, sweet clover appears to be a promising source of bioactive compounds and mineral elements for the fortification of fermented dairy products. However, there is still limited information on how the incorporation of sweet clover extract into yogurt affects the content of polyphenols, flavonoids and mineral elements, as well as the safety indicators related to toxic elements, in comparison with both the original plant material and the extract itself. Addressing this gap is important for substantiating the use of sweet clover extract as a functional ingredient and for optimising the formulation of enriched yogurts with improved nutritional and health-related properties.

Therefore, the present study focuses on a comparative assessment of bioactive compounds (polyphenols and flavonoids), essential mineral elements and toxic elements in sweet clover raw material, sweet clover extract and yogurt enriched with this extract, with the aim of evaluating their potential for the development of safe and nutritionally enhanced functional dairy products.

II. MATERIAL AND METHODS

A. Sample preparation

Cow's milk was used as the main raw material for yogurt production. The starter culture MicroMilk Yo (Italy) was used for fermentation. Milk was inoculated with the starter culture and incubated at 37°C for 7–8 h until coagulation was completed. After fermentation, sweet clover (*Melilotus officinalis*) extract was added to the experimental yogurt sample at 0.3% of the total mass, while the control yogurt was produced without extract addition. The study included two yogurt samples: control yogurt and yogurt enriched with sweet clover extract (Figure 1).



Fig. 1 Samples of yogurts

B. Total phenolic compounds (TPC)

The amount of phenolic compounds was performed by using the Folin-Chocalteu colorimetric method. Briefly, 10 g of the sample yogurt was centrifuged at 5000 rpm for 15 min. Then to 0.1 mL of the supernatant 2 mL of sodium carbonate solution and 0.1 mL of Folin-Chocalteu reagent were added. After 2h of incubation period the absorbance of the samples was measured at 750 nm using spectrophotometer UV-1900i (Shimadzu, Japan). The TPC was measured by calibration curve and expressed as mg of Gallic acid equivalents per kg of yogurt (mg GAE/kg) [7].

C. Antioxidant activity (ABTS)

The antioxidant activity of yogurt samples was determined using the ABTS radical cation (ABTS-⁺) scavenging assay according to the method described by Huang et al. (2025) with minor modifications. Briefly, ABTS-⁺ working solution was prepared by reacting 7.0 mM ABTS with 2.45 mM potassium persulfate in the dark at room temperature for 12–16 h and then diluting the mixture with ethanol (or phosphate buffer) to obtain an absorbance of 0.70 ± 0.02 at 734 nm. An aliquot of yogurt extract was mixed with the ABTS-⁺ solution, incubated for 6 min at room temperature, and the decrease in absorbance at 734 nm was measured using a spectrophotometer. The ABTS scavenging capacity was expressed as Trolox equivalent antioxidant capacity (TEAC, μmol Trolox equivalents per g of sample) based on a calibration curve constructed with Trolox standard solutions [8].

D. Elemental composition

Mineral elements, including Ca, K, Mg, P, Fe, Zn, and Se, were determined by atomic absorption spectrometry according to ISO 6869:2000 “Animal feeding stuffs — Determination of the contents of calcium, copper, iron, magnesium, manganese, potassium, sodium and zinc — Method using atomic absorption spectrometry” [9]. Toxic elements were determined using nationally standardized methods for food raw materials and products: Pb and Cd were measured by atomic absorption spectrometry following GOST 30178-96 [10], As was determined by a colorimetric method according to GOST 26930-86 [11], and Hg was quantified according to GOST 26927-86 [12]. These validated procedures are widely applied in routine food safety control to verify compliance with regulatory limits for toxic elements in foods.

E. Data handling

All measurements were performed in triplicate.

Results were expressed as mean \pm standard deviation; differences between control and fortified yogurt were evaluated based on graphical comparison and significance markers (e.g., asterisks) derived from the underlying statistical testing plan adopted by the laboratory.

III. RESULTS

Bioactive compounds of the samples

Bioactive compounds in the yogurt samples were evaluated based on total phenolic content (TPC, mg GAE/kg) and antioxidant capacity measured by the ABTS assay (μmol TEAC/g). The enrichment of yogurt with sweet clover extract led to a moderate increase in TPC: from 1280 mg GAE/kg in the control yogurt to 1340 mg GAE/kg in the yogurt containing 0.3% extract (Figure TPC). This difference, highlighted by the significance marker on the graph, indicates that the addition of the plant extract effectively enhances the pool of phenolic compounds in the fermented milk matrix. At the same time, the error bars for both samples remain relatively narrow, suggesting good repeatability of the measurements and a robust effect rather than random variation. (Figure 2).

The ABTS radical cation scavenging assay showed a more pronounced difference between the samples. The control yogurt exhibited an antioxidant capacity of 50.8 μmol TEAC/g fresh weight, whereas the yogurt enriched with sweet clover extract reached 71.7 μmol TEAC/g (Figure ABTS). Thus, the introduction of the extract resulted in an increase of about 41% in TEAC values, which is consistent with the higher TPC and confirms the functional contribution of sweet clover

phenolics to the overall radical-scavenging activity of the product. The graphical comparison clearly demonstrates that the enriched yogurt has both higher phenolic content and stronger antioxidant capacity than the control, supporting its classification as a functional dairy product with improved bioactive properties (Figure 3).

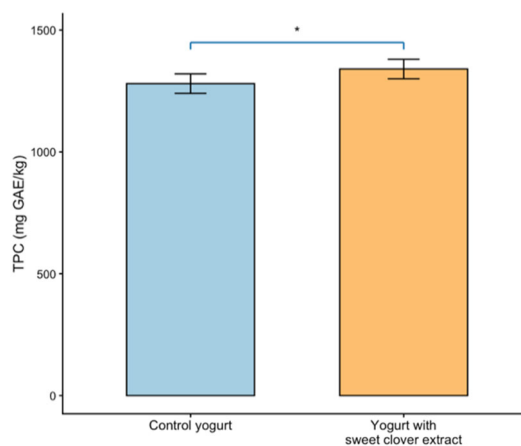


Fig.2 TPC content in yogurt

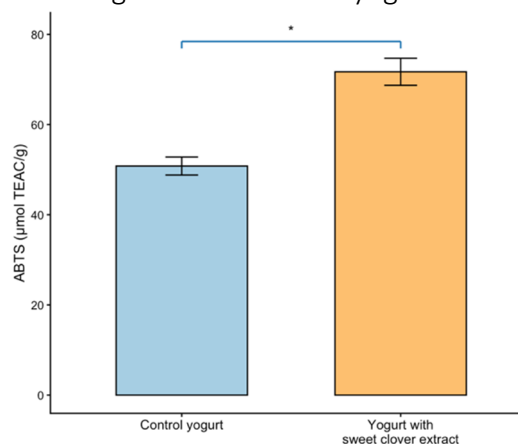


Fig.3 ABTS compounds in yogurt

B. Elemental composition of yogurt

Elemental composition in yogurt was assessed by determining the content of essential mineral elements (Figure 4) and toxic elements in the control yogurt and the yogurt enriched with sweet clover extract. According to the testing protocol, both samples contained appreciable amounts of calcium (Ca), potassium (K), magnesium (Mg), phosphorus (P), iron (Fe) and zinc (Zn), while selenium (Se) was not detected in either yogurt. In the control yogurt, Ca, K and P formed the main part of the mineral fraction, reflecting the typical composition of fermented cow's milk, with lower levels of Mg, Fe and Zn. In the yogurt with sweet clover extract, Ca content remained high and even slightly increased compared with the control, while K, Mg and P also showed modestly higher values, indicating that the combination of milk matrix and plant extract provides a more favourable mineral profile.

The distribution of trace elements demonstrated that Fe and Zn were present in both samples at low but nutritionally relevant concentrations. The enriched yogurt showed a slight increase in Zn compared with the control, which can be considered an additional benefit from the standpoint of micronutrient supply, given the role of Zn in immune function and antioxidant defence. At the same time, the absolute differences in Fe and Zn between the two yogurts were not as pronounced as those observed for Ca and K, suggesting that the dairy base remains the main source of these elements, while the contribution of the extract is secondary. Overall, the

mineral composition data indicate that enrichment with sweet clover extract does not dilute the intrinsic mineral value of yogurt and may slightly enhance the levels of some macro- and microelements.

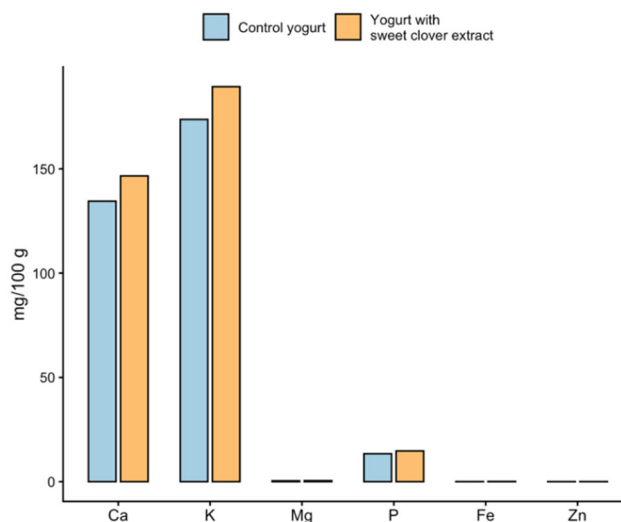


Fig. 4 Mineral elements in yogurt samples

Special attention was paid to the safety of the products in terms of toxic elements. Lead (Pb), cadmium (Cd), arsenic (As) and mercury (Hg) were either not detected or were present at levels far below the maximum permissible limits established for food products. In the control yogurt, Pb and Cd were below the detection limit, and As and Hg were not detected, confirming the safety of the raw materials and processing conditions. A similar pattern was observed in the yogurt supplemented with sweet clover extract: Pb, Cd, As and Hg were not detected, which shows that the introduction of the plant extract did not introduce additional contamination by toxic elements. These findings are in line with the values recorded for the original plant material and extract, where the measured concentrations of Pb and Cd were well below regulatory thresholds and As and Hg were absent.

IV. DISCUSSION

A. *Bioactive compounds of the samples*

The observed increase in TPC (from 1280 to 1340 mg GAE/kg) and ABTS antioxidant capacity (from 50.8 to 71.7 $\mu\text{mol TEAC/g}$) after enrichment of yogurt with sweet clover extract is consistent with results reported for other plant-fortified yogurts. For example, yogurts fortified with pomegranate peel extract or wild berry preparations typically show higher TPC and significantly enhanced ABTS or DPPH radical scavenging activity compared with control samples, although the magnitude of the effect depends strongly on extract type and dosage. In this context, the approximately 41% increase in ABTS value found in the present study places sweet clover-enriched yogurt within the range of antioxidant enhancement reported for yogurts supplemented with fruit peels, herbal extracts or polyphenol-rich plant matrices [13-15].

The disproportionate rise in ABTS activity relative to the moderate increase in TPC suggests that qualitative aspects of the phenolic profile are also important. Sweet clover species are known to contain coumarin, flavonoids and phenolic acids with pronounced antioxidant properties, and recent reviews have highlighted *Melilotus* spp. as promising sources of bioactive compounds [1,3,4].

Overall, the comparison with international studies supports the conclusion that sweet clover extract is a competitive plant ingredient for the development of antioxidant-enriched fermented dairy products.

B. *Elemental composition of yogurt*

The elemental composition of both yogurt samples was characterized by a typical dairy mineral profile with calcium and potassium as the predominant macroelements, followed by phosphorus and magnesium, and lower levels of iron and zinc. This pattern agrees with published data on conventional and functional yogurts, where Ca, K and P generally account for the main part of the mineral fraction, while Fe and Zn are present as trace elements that nevertheless contribute to the overall nutritional value. Fortification with sweet clover extract did not reduce the intrinsic mineral value of the product; instead, the enriched yogurt showed slightly higher concentrations of Ca, K, Mg and P compared with the control, indicating that the combination of milk matrix and plant extract can provide a more favourable mineral profile. Similar modest increases in selected minerals have been reported for yogurts fortified with plant-based ingredients or herbal preparations, where the plant component contributed additional macro- and microelements without diluting the native mineral content of milk [16-17].

From a safety perspective, the absence or extremely low levels of toxic elements (Pb, Cd, As, Hg) in both samples confirm that neither the dairy raw material nor the sweet clover extract introduces significant contamination risks. Measured concentrations were below detection limits or far below regulatory thresholds, which is consistent with studies analysing the quality and safety of yogurts and other fermented milk products, where compliance with heavy metal limits is a key criterion for product acceptability.

Taken together, these findings support the conclusion that yogurt enriched with sweet clover extract combines a slightly improved mineral profile with full compliance to safety requirements regarding toxic elements, thereby maintaining both nutritional and hygienic quality at a high level.

V. CONCLUSION

The results of this study demonstrated that the incorporation of sweet clover (*Melilotus officinalis*) extract into yogurt improved its functional characteristics without compromising product safety. The enriched yogurt showed a higher total phenolic content (1340 mg GAE/kg) and stronger antioxidant activity measured by the ABTS assay (71.7 $\mu\text{mol TEAC/g}$) compared with the control sample, confirming the contribution of sweet clover extract to the bioactive profile of the fermented dairy matrix. This trend is consistent with published studies showing that plant-derived ingredients can effectively enhance the antioxidant potential of yogurt and increase its value as a functional food.

In addition to antioxidant improvement, the yogurt enriched with sweet clover extract maintained a favourable mineral composition, with slightly higher levels of calcium, potassium, magnesium and phosphorus than the control sample. At the same time, toxic elements such as Pb, Cd, As and Hg were not detected in the final product, indicating full compliance with safety requirements and confirming that the addition of sweet clover extract did not introduce contamination risks. Therefore, sweet clover extract can be considered a promising natural ingredient for the development of functional yogurts with enhanced biological value, antioxidant potential and satisfactory elemental safety profile.

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ЗАМАНАУИ LMS-ЖҮЙЕЛЕРІНІҢ АҚПАРАТТЫҚ ҚАУІПСІЗДІГІН ҚАМТАМАСЫЗ ЕТУДІҢ БАЗАЛЫҚ АСПЕКТИЛЕРІ

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Аңдатпа. Оқыту басқару жүйелері (Learning Management Systems, LMS) білім беру экожүйесінде маңызды рөл атқарады, өйткені олар оқу материалдарына қол жеткізуді, білім беру процесіне қатысушылар арасындағы өзара байланысты және оқу деректерін басқаруды қамтамасыз етеді. Алайда бұл жүйелердің кеңінен қолданылуы киберқауіптер санының артуымен қатар жүреді, сондықтан ақпараттық қауіпсіздік мәселелері аса өзекті болып отыр.

Мақалада LMS жүйелеріндегі деректерді қорғаудың негізгі аспектілері қарастырылады, олардың ішінде SQL-инъекциялар, кросс-сайттық скриптинг (XSS), DDoS-шабуылдар және рұқсатсыз қол жеткізу сияқты қауіптер бар. Қауіпсіздікті қамтамасыз ету әдістері талданады, соның ішінде деректерді шифрлау, көпфакторлы аутентификация, бағдарламалық қамтамасыз етуді үнемі жаңарту және етуге тестілеу (penetration testing).

Платформалардың қауіпсіздігін қамтамасыз етудегі пайдаланушылардың рөліне және олардың киберқауіптер туралы хабардарлығын арттыру қажеттілігіне ерекше назар аударылады. Ұсынылған шаралар цифрландыру жағдайында құпия ақпаратты сенімді қорғауды қамтамасыз етуге және тәуекелдерді азайтуға бағытталған.

Түйін сөздер: Оқу басқару жүйелері (LMS), SQL инъекциялары, Сайт аралық скриптинг (XSS), DDoS шабуылдары, Canvas LMS (АҚШ), Moodle LMS, Blackboard LMS, Moodle (Ұлыбритания), Google Classroom

Кіріспе. LMS жүйесіндегі ақпараттық қауіпсіздік – бұл ақпаратты рұқсатсыз қол жеткізуден, өзгертілуден, жойылудан немесе ұрланудан қорғауға бағытталған кешенді шаралар жиынтығы. Бұл әртүрлі технологиялар мен саясаттарды қолдану арқылы жүзеге асырылады, мысалы: деректерді шифрлау, қол жеткізуді бақылау жүйелері, сондай-ақ зиянды бағдарламаларды анықтап, олардың алдын алуға арналған бағдарламалық жасақтама.

LMS жүйесіндегі ақпаратты қорғау әдістері

Ақпаратты қорғау үшін келесі әдістер қолданылады:

1. Қауіпсіз платформаны таңдау:

LMS платформасын таңдағанда, оның сенімді қауіпсіздік функциялары – деректерді

шифрлау, қол жеткізуді бақылау және көпфакторлы аутентификация – бар екеніне көз жеткізу қажет.

2. Қол жеткізуді бақылау құралдары:

Рөлдерге негізделген қол жеткізу саясатын (RBAC) енгізу арқылы құпия ақпаратқа тек уәкілетті адамдардың ғана кіруіне мүмкіндік беріледі.

3. Деректерді шифрлау:

Деректерді интернет арқылы тасымалдау кезінде оларды SSL/TLS протоколдары арқылы шифрлау ақпаратты қорғауға көмектеседі.

4. Жүйені тұрақты түрде жаңарту және түзетулер енгізу:

LMS платформасын үнемі жаңартып отыру және осал тұстарын түзету жүйедегі белгілі қауіпсіздік кемшіліктерін жоюға және шабуылдардың алдын алуға көмектеседі.

Қауіпсіздікті бағалау және енуге тестілеу

Қауіпсіздікті тұрақты бағалау, мысалы, осалдықтарды сканерлеу және енуге тестілеу (penetration testing), ақпараттық қауіпсіздікке төнетін ықтимал қатерлер мен осал тұстарды анықтауға көмектеседі [1].

LMS-тің білім беру экожүйесіндегі рөлі

LMS жүйелері университеттер мен компаниялардың білім беру экожүйесінде негізгі орын алады. Олар тек оқытуды ғана емес, сонымен қатар аналитика мен коммуникацияны да қамтамасыз етеді. Алайда, LMS-ті енгізу мұқият жоспарлауды және қолданыстағы бизнес-процестерге бейімдеуді талап етеді. Бұл – тәуекелдерді азайту және нәтижелерді оңтайландыру үшін маңызды.

Материалдар мен әдістер. LMS жүйелеріндегі ақпараттық қауіпсіздік – заманауи білім берудің аса маңызды құрамдас бөлігі. Ақпаратты киберқауіптерден қорғау үздіксіз дамуды және жаңа технологиялар мен қауіпсіздік саясатын енгізуді қажет етеді. Ұйымдар өздерінің ақпараттық активтерінің тұрақтылығы мен қауіпсіздігін қамтамасыз ету үшін қауіптерді бағалауға және оларды барынша азайтатын тиімді шараларды әзірлеуге ерекше назар аударуы керек.

Анализ қауіптер киберқауіпсіздік саласында жоғары оқу орындарында қашықтан оқыту кезінде COVID-19 пандемиясы жоғары оқу орындарының (ЖОО) қашықтан оқытуға жаппай көшуіне себеп болды, бұл бұлтты технологиялардың, онлайн-платформалардың және бейнеконференциялардың қолданылуын айтарлықтай арттырды. Алайда, бұл процесс сонымен бірге киберқауіптерді, мысалы, DDoS-шабуылдары, межсайты скрипттеу (XSS), спуфинг, рұқсатсыз кіру және жеке деректерді ұрлау сияқты қауіптерді арттырды.

Қашықтан оқытудың негізгі технологиялары бұлтты есептеулер (IaaS, PaaS, SaaS), оқыту басқару жүйелері (LMS) және бейнеконференция қызметтері (VCA) болып табылады. Киберқауіпсіздікті арттыру үшін ЖОО жүйелерін жаңарту, қауіпсіздік патчтарын басқару, қолжетімділік саясатын енгізу, деректерді жіктеу және криптографиялық протоколдарды қолдану қажет [2].

Оқыту басқару жүйелеріне (LMS) жасалған нақты кибершабуылдардың мысалдары [4–8]

Күні	Мақсаты	Шабуыл түрі	Салдары
06.2020	Canvas LMS (CША)	Құпиялылықтың бұзылуы [4]	Студенттердің әрекеттері мен жеке деректері туралы ақпаратты жинағаны үшін сотқа шағым түсті.
01.2022	Moodle LMS	SQL инъекциясы [5]	Деректер базасын басып алу қаупі және құпия ақпараттың таралуы
07.2020	Blackboard LMS	Ransomware [6]	5 миллионнан астам пайдаланушыны қамтыған деректерді шифрлау және олардың таралуы
02.2024	Moodle (UK)	DDoS-шабуылы[7]	Қызметтің істен шығуы және онлайн оқуға қол жеткізудегі кідірістер
08.2022	Google Classroom	Фишинг [8]	Жалған кіріс беттері мен фишингтік құжаттар арқылы тіркелгі деректерін ұрлау

Нәтижелер. LMS жүйелерінің осалдығы және білім беру платформаларының қауіпсіздігіне әсері

Қазіргі заманғы оқыту басқару жүйелері (LMS) білім беру процесінде маңызды рөл атқарады, әсіресе COVID-19 пандемиясы кезінде онлайн оқытуға жаппай көшу жағдайында. Алайда, LMS жүйелерінің кеңінен қолданылуы кибершабуылдардың санының артуына әкелді, бұл олардың қауіпсіздігі мәселесін өте өзекті етеді.

Зерттеу Moodle, SAP Litmos және TalentLMS сияқты танымал LMS жүйелерінің осалдықтарын анықтауға бағытталған. Қауіп деңгейін бағалау үшін OWASP Top 10 және Common Vulnerability Scoring System (CVSS) стандарттары қолданылды. Талдау тестілеу ортасында Nmap, OpenVAS және Tenable.io құралдары арқылы жүргізілді.

Зерттеу нәтижелері негізгі мәселелердің қатарына қатаң тасымалдау қауіпсіздігі саясатының (HSTS) болмауын, Cross-Site Scripting (XSS) осалдығын, ескірген кітапханаларды қолдануды және HTTP тақырыптарын қорғаудың жеткіліксіздігін қамтиды. Бұл факторлар студенттердің деректерінің ағып кетуіне және оқу материалдарының бұзылуына әкелуі мүмкін.

LMS қауіпсіздігін арттыру үшін заманауи қорғау протоколдарын енгізу, бағдарламалық қамтамасыздандыруды тұрақты түрде жаңарту және HTTPS конфигурациясын баптау ұсынылады. Білім беру мекемелері платформаларды енгізбес бұрын олардың қауіпсіздік деңгейін ескеріп, тәуекелдерді барынша азайтуы қажет [3].

Киберқауіпсіздік оқыту басқару жүйелерінде (LMS) білім беру саласында

Қазіргі уақытта қашықтан оқыту технологиялары білім беру процесінің ажырамас бөлігіне айналды. Moodle сияқты электронды платформалар студенттер мен оқытушыларға өзара әрекеттесуге, оқу материалдарын бөлісуге және онлайн сабақтар өткізуге мүмкіндік береді. Алайда, LMS жүйелерінің танымалдылығының өсуімен бірге киберқатерлердің саны да артты, бұл қауіпсіздік мәселелерін ерекше маңызды етеді.

LMS жүйелеріндегі киберқауіпсіздіктің негізгі мәселелерінің бірі — пайдаланушылардың деректерін қорғау. Қашықтан оқыту платформалары студенттердің, оқытушылардың және әкімшілік қызметкерлердің жеке ақпаратын, соның ішінде аттар, парольдер мен академиялық жазбаларды өңдейді. Егер қорғау жеткіліксіз болса, бұл

деректер қаскүнемдер тарапынан шабуылдардың нысанасына айналуы мүмкін. Мысалы, кең таралған бұзушылық әдістері арасында brute-force шабуылдары (парольдерді қолмен тауып алу), SQL инъекциялары (деректер базасын бұзу) және межсайты скрипттеу (XSS), бұл хакерлерге платформаның веб-беттеріне зиянды кодтарды енгізуге мүмкіндік береді [4].

Қашықтан оқыту жүйелерінде (LMS) киберқауіптермен қатар ішкі тәуекелдер де бар. Қол жетімділікті дұрыс басқармау, пайдаланушылардың әлсіз паролдері және деректерді шифрлаудың болмауы ақпараттың ағып кетуіне әкелуі мүмкін. Платформаның қауіпсіздігі тек әзірлеушілерге ғана емес, сонымен бірге пайдаланушыларға да байланысты екенін түсіну маңызды. Мысалы, егер студент әлсіз пароль қолданса немесе өзінің тіркелгі деректерін үшінші тұлғаларға берсе, ол тек өз тіркелгісін ғана емес, бүкіл жүйені де тәуекелге ұшыратады.

LMS қауіпсіздігін арттыру үшін кешенді қорғау шараларын енгізу қажет. Біріншіден, хакерлердің есептік жазбаларға қол жеткізуін қиындататын көпфакторлы аутентификацияны қолдану маңызды. Екіншіден, жүйелерді тұрақты түрде жаңартып отыру керек, себебі ескірген бағдарламалық қамтамасыздандыруда хакерлер пайдалануы мүмкін осалдықтар бар. Үшіншіден, деректерді тасымалдау және сақтау кезінде шифрлау қажет, өйткені бұл олардың ұрлануынан немесе рұқсатсыз қолданылуынан қорғауға көмектеседі [5].

Техникалық қорғау шараларымен қатар, пайдаланушылардың ақпараттану деңгейін арттыру да маңызды. Оқытушылар мен студенттерге киберқауіпсіздіктің негіздерін үйрету көптеген адам факторымен байланысты шабуылдардың алдын алуға көмектеседі. Мысалы, фишингтік шабуылдар туралы білім (қаскүнемдер ресми платформаның өкілдері болып көрініп, деректерді сұрайды) пайдаланушыларға алаяқтардың аяласына түсіп қалмауға мүмкіндік береді.

Киберқауіпсіздік жоғары оқу орындарында: қиындықтар мен шешімдер

Цифрландыру дәуірінде білім беру процесі күннен күнге онлайн форматқа көшууде. Қашықтан оқыту, виртуалды зертханалар және оқыту басқару жүйелері (LMS) студенттер мен оқытушыларға жаңа мүмкіндіктер ашады. Алайда, технологиялардың дамуы киберқауіптердің санын арттырып, деректердің құпиялығын, оқу процесінің тұтастығын және білім беру платформаларының тұрақтылығын қауіпке душар етеді.

Жоғары оқу орындарында киберқауіпсіздіктің негізгі мәселелерінің бірі — деректерге рұқсатсыз кіру. Университеттерде студенттердің құпия ақпараты, ғылыми зерттеулер және әкімшілік құжаттар сақталады. Олардың ағып кетуі ауыр салдарға әкелуі мүмкін, соның ішінде академиялық деректердің бұрмалануы мен білім беру жүйесіне деген сенімнің жоғалуы. Сонымен қатар, қашықтан оқыту платформалары фишинг, парольдер бұзу және DDoS-шабуылдары сияқты шабуылдарға ұшырайды, бұл оқу процесін тоқтатып тастауға себеп болуы мүмкін [6].

Бұл мәселелерді шешу үшін кешенді қорғау шараларын қолдану қажет. Біріншіден, заманауи аутентификация әдістерін енгізу, мысалы, көпфакторлы сәйкестендіру және биометриялық технологиялар. Екіншіден, университеттер деректерді тасымалдау кезінде де, сақтау кезінде де ақпаратты қорғау үшін шифрлауды қолдануы тиіс. Үшіншіден, оқыту басқару жүйелерін жүйелі түрде жаңартып, анықталған осалдықтарды жою қажет.

Алайда, техникалық шаралар өздігінен абсолютті қауіпсіздікті қамтамасыз етпейді. Пайдаланушылардың ақпараттануы маңызды рөл атқарады. Оқытушылар мен студенттер әлсіз паролдерді, ашық Wi-Fi желілерін және күмәнді ақпарат көздерін пайдалану тәуекелдерін түсінуі керек. Сондықтан университеттер киберқауіпсіздік бойынша білім беру бағдарламаларын енгізіп, тұрақты тренингтер өткізуі тиіс.

Жоғары оқу орындарындағы деректердің қауіпсіздігі кешенді көзқарасты талап етеді, оның ішінде техникалық, ұйымдық және білім беру шаралары бар. Тек барлық қатысушылардың белсенді өзара әрекеттесуінің арқасында ғана ақпаратты қорғаудың

сенімді жүйесін құрып, қашықтан оқытудың қауіпсіздігі мен үздіксіздігін қамтамасыз етуге болады [7].

Жоғары білім беру саласындағы BYOD жүйесіндегі киберқауіптер

BYOD (Bring Your Own Device) саясатын жоғары оқу орындарында енгізу студенттер мен оқытушылардың білім беру ресурстарына қол жеткізуін айтарлықтай жеңілдетті. Алайда, жеке құрылғыларды оқыту басқару жүйелеріне (LMS) қосу киберқауіпсіздік тұрғысынан елеулі қауіптер туғызады.

Негізгі мәселелер құрылғылардың ұрлануы, деректердің ағып кетуі, қорғалмаған желілер мен зиянды бағдарламалық жасақтаманы қолдану болып табылады. Қауіпсіздік саясатының жеткіліксіздігі және студенттердің құрылғыларын бақылаудың әлсіздігі жағдайды одан әрі нашарлатады. Зерттеулерге сәйкес, студенттер мен қызметкерлердің 70%-ы рұқсат етілмеген қосымшаларды пайдаланады, бұл құпия ақпараттың бұзылуына әкелуі мүмкін [8].

LMS қауіпсіздігін арттыру үшін кешенді шараларды қолдану қажет: деректерді шифрлау, көпфакторлы аутентификация, жүйені тұрақты бақылау және пайдаланушыларды кибергигиенаға үйрету. Университеттер BYOD қолдану саясатын нақты әзірлеп, оның қатаң сақталуын қамтамасыз етуі керек.

BYOD білім беруде ыңғайлылықты қамтамасыз етумен қатар, ақпараттық қауіпсіздік тұрғысынан үлкен сын-тегеурін болып табылады. Тек технологияларды, саясатты және пайдаланушылардың ақпараттануын біріктіретін кешенді тәсіл ғана қауіптерді азайтып, деректерді қорғаудың сенімді жүйесін құруға мүмкіндік береді [9].

Ақпараттық қауіпсіздіктің тәуекелдерін бағалаудың бұлыңғыр сараптамалық жүйесі

Қазіргі заманғы ақпараттық жүйелер, әсіресе оқыту басқару жүйелерінде (LMS), қауіпсіздікке қатысты көптеген қатерлерге тап болады. Дәстүрлі тәуекелдерді бағалау әдістері жиі жеткіліксіз икемді болып қалады, бұл ұйымдардың осалдықтарына және қаржылық шығындарына әкеледі. Бұл мақалада ақпараттық қауіпсіздіктің тәуекелдерін бағалаудың жаңа тәсілі ұсынылады, ол бұлыңғыр логикаға негізделген.

Негізгі идея тәуекелдерді бағалау модельдерінің иерархиялық құрылымын құруда, олар Мамданидің алгоритміне негізделген 15 бұлыңғыр машинаны қолданады. Бұл машиналар қауіпсіздіктің әртүрлі аспектілерін талдайды: ұйымдық, беделдік, құпиялылық, ақпараттың тұтастығы және қолжетімділігі. Мұндай тәсіл жүйелердің қауіпсіздігіне әсер ететін факторлардың белгісіздігін және өзгергіштігін ескеру мүмкіндігін береді.

Талқылау. Эксперименттер барысында жүйе түрлі оқыту басқару платформаларында, соның ішінде Platonus, Canvas және Moodle жүйелерінде тестіленді. Алынған нәтижелер NIST 800-30 және ISO/IEC 13335-3:1998 сияқты дәстүрлі тәуекелдерді бағалау әдістерімен жоғары корреляцияны көрсетті. Бұл ұсынылған модельдің тиімділігін және оның ERP, банктік және медициналық жүйелерді қоса алғанда күрделі жүйелердегі тәуекелдерді бағалауға жарамдылығын растайды.

Бұл әдіс тәуекелдерді бағалау процесін автоматтандыруға және ақпараттық қауіпсіздіктің деңгейін арттыруға мүмкіндік береді, бірақ оның енгізілуі жоғары білікті сарапшылар мен үлкен есептеу ресурстарын талап етеді [10].

Оқыту басқару жүйелерінің қауіпсіздігі: осалдықтарды талдау және қорғау

Оқыту басқару жүйелері (LMS) білім беру саласында кеңінен қолданылады, бірақ олар жиі кибершабуылдар үшін осал болып табылады. «Security Analysis of Learning Management System Using Penetration Testing with ISSAF Framework» мақаласында LMS қауіпсіздігі мәселесі ISSAF Framework әдісі бойынша тестілеу әдісін қолдану арқылы зерттеледі.

Қорытынды. Авторлар LMS жүйелері SQL-инъекциялар, XSS және кликджеккинг сияқты шабуылдарға ұшырайтынын және оларда әлсіз қауіпсіздік саясаттары бар екенін

анықтады. Тестілеу барысында деректердің ағып кетуіне және рұқсатсыз қол жеткізуге әкелуі мүмкін критикалық осалдықтар табылды.

Қауіпсіздікті арттыру үшін XSS-ке қарсы қорғауды, сенімді HTTP заголовкаларын, деректерді шифрлауды және пайдаланушылардың аутентификациясын күшейтуді ұсынды. LMS жүйелерін үнемі тестілеу және пайдаланушылардың ақпараттануын арттыру шабуылдардың тәуекелдерін азайтуға көмектеседі. LMS қауіпсіздігі — цифрлық білім берудің маңызды аспектісі, ол тұрақты бақылауды және қорғау әдістерін жетілдіруді талап етеді.

Бұлтты LMS жүйелеріндегі деректер қауіпсіздігін арттыру

Бұлтты оқыту басқару жүйелері (LMS) білім беру саласында кеңінен қолданылады, бірақ кибершабуылдарға осал болып қалуда. «Enhancing Data Security of Cloud-Based LMS» мақаласында деректерді қорғау әдісі криптография (AES, Blowfish, RC6, BRA) және LSB-стеганографиясын пайдалану арқылы ұсынған. Кілттерді сақтау үшін бұл әдіс қолданылады.

LMS негізгі қатерлері — рұқсатсыз қол жеткізу, деректердің ағып кетуі және жеткіліксіз аутентификация. Авторлар шифрлауды және дешифрлауды 10–15%-ға жылдамдататын модельді әзірледі, бұл шабуылдар тәуекелін азайтады. Қосымша қорғау үшін VPN, SSL және HTTPS ұсынылады.

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МЕТОДЫ ЗАЩИТЫ И ОБЕСПЕЧЕНИЯ НАДЕЖНОСТИ МОДЕЛЕЙ МАШИННОГО ОБУЧЕНИЯ НА ОСНОВЕ ДАННЫХ СОЦИАЛЬНЫХ СЕТЕЙ

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АННОТАЦИЯ

В данной статье мы комплексно исследуем вопросы обеспечения безопасности моделей машинного обучения, использующих данные социальных сетей. В ходе исследования анализируются атаки инверсии модели, атаки отравления, атаки Sybil, обнаружение спам-кампаний, атаки деанонимизации и стратегии федеративного обучения (federated learning).

Исследование опирается на пять основных научных трудов: Benevenuto и др. Описывающих поведение пользователей в социальных сетях; Kayes и Iamnitchi, всесторонне рассмотревших вопросы конфиденциальности и безопасности в сетевых системах; McMahan и др. Предложивших алгоритм федеративного обучения; Fredrikson и др., исследовавших атаки инверсии модели; Jiang и др., изучавших гибкие атаки отравления.

Результаты исследования выявили основные уязвимости моделей машинного обучения и оценили эффективность защитных механизмов путем сравнительного анализа. Технология федеративного обучения значительно повышает безопасность сетевых систем, обеспечивая децентрализованное обучение на данных.

Ключевые слова: машинное обучение, социальные сети, безопасность, атака отравления, инверсия модели, федеративное обучение, дифференциальная конфиденциальность, атака Sybil, деанонимизация, безопасность данных.

Keywords: machine learning, social networks, security, poisoning attack, model inversion, federated learning, differential privacy, Sybil attack, de-anonymization, data security.

ВЕДЕНИЕ

Развитие технологий искусственного интеллекта и машинного обучения приобрело особый размах за последние десять лет. Сегодня алгоритмы машинного обучения широко применяются во всех сферах жизни, таких как медицина, финансы, национальная безопасность, транспорт и электронная коммерция. Для работы этих алгоритмов требуются огромные объемы данных. Однако противоречие между доступностью данных и их

чувствительностью сделало безопасность систем машинного обучения первоочередной проблемой.

Как отмечают Kayes и Iamnitchi, онлайн-социальные сети на сегодняшний день стали постоянной частью как личной, так и профессиональной жизни миллионов интернет-пользователей. В 2014 году в Facebook было 1.32 миллиарда ежемесячно активных пользователей, и он стал вторым по популярности сайтом в интернете. Twitter зарегистрировал более 500 миллионов пользователей. Эти гигантские ресурсы данных используются для обучения моделей машинного обучения, но в то же время открывают скрытые возможности для злоумышленников.

Системы машинного обучения, основанные на данных социальных сетей, могут подвергаться нескольким серьезным угрозам:

- Во-первых, атаки отравления (poisoning attacks) – злоумышленник пытается скомпрометировать модель, добавляя вредоносные примеры в обучающие данные.
- Во-вторых, атаки инверсии модели (model inversion attacks) – злоумышленник, используя доступ к модели, пытается восстановить личную информацию, использованную в обучающих данных.
- В-третьих, атаки деанонимизации – попытка раскрытия личности пользователя путем сопоставления изначально анонимизированных данных с внешней базой данных.
- В-четвертых, атаки Sybil – один злоумышленник создает несколько фальшивых аккаунтов, пытаясь установить избыточное влияние в системе.

Jiang и др. (2019), создавая таксономию атак на машинное обучение, разделили атаки отравления на атаки на целостность (integrity attacks) и атаки на доступность (availability attacks). Они доказали, что путем внедрения вредоносных образцов в обучающие данные обученную модель можно исказить так, чтобы она была выгодна злоумышленнику. Fredrikson и др. (2015), исследуя возможности извлечения личной информации из интерфейсов машинного обучения, показали, что такие атаки в моделях дерева решений осуществляются с нулевым уровнем ложноположительных результатов, а из систем распознавания лиц изображение лица можно восстановить с высокой точностью. McMahon и др. предложили подход федеративного обучения (federated learning) для машинного обучения на основе данных, собираемых с мобильных устройств. Предложенный ими алгоритм FederatedAveraging (FedAvg) позволяет обучать модели без централизации данных. Этот подход значительно усиливает защиту конфиденциальности за счет отправки только обновлений модели, без передачи самих данных на сервер.

Цели и задачи исследования

Основной целью данного исследования является всесторонний анализ уязвимостей безопасности моделей машинного обучения, использующих данные социальных сетей, и разработка комплекса эффективных методологических подходов для их устранения.

Задачи исследования:

- Классификация основных видов атак, направленных на системы машинного обучения, и изучение их особенностей.
- Измерение эффективности атак отравления с помощью численных моделей и оценка их результатов.
- Анализ роли технологии федеративного обучения в безопасности.
- Исследование атак инверсии модели и деанонимизации с помощью численных экспериментов.
- Оценка эффективности механизмов защиты конфиденциальности и формулирование конкретных рекомендаций.

МЕТОДОЛОГИЯ И МЕТОДЫ ИССЛЕДОВАНИЯ

Согласно исследованию Deep Learning, модели глубокого обучения могут быть уязвимы к adversarial-атакам, при которых злоумышленники изменяют входные данные для получения ошибочного результата классификации. Авторы подчеркивают необходимость использования устойчивых алгоритмов обучения и регуляризации моделей.

Исследование состоит из нескольких этапов: обзор литературы, определение основных понятий и уязвимостей; описание моделей атак на формальном математическом языке; проектирование архитектуры федеративного обучения; формирование экспериментального стенда и проведение численных оценок; анализ результатов и формулирование рекомендаций. Исследование проводилось в междисциплинарном направлении. Оно находится на стыке таких дисциплин, как информационная безопасность, машинное обучение, исследование социальных сетей и математическая статистика.

Системы машинного обучения, основанные на данных социальных сетей, могут подвергаться нескольким серьезным угрозам. Во-первых, атаки отравления (poisoning attacks) — злоумышленник пытается скомпрометировать модель, добавляя вредоносные примеры в обучающие данные. Во-вторых, атаки инверсии модели (model inversion attacks) — злоумышленник, используя доступ к модели, пытается восстановить личную информацию, использованную в обучающих данных. В-третьих, атаки деанонимизации пытаются раскрыть личность человека.

Алгоритм	IID MNIST (CNN)	Non-IID MNIST	Shakespeare LSTM
FedSGD (базовый)	626 итераций	483 итерации	3906 итераций
FedAvg (E=5, B=50)	29 итераций	334 итерации	152 итерации
FedAvg (E=20, B=10)	18 итераций	173 итерации	41 итерация
Ускорение (FedAvg/FedSGD)	~34.8x	~2.8x	~95.3x

Таблица 1. Эффективность алгоритма FedAvg в сокращении коммуникационных итераций (данные McMahan и др., 2017)

Математические основы атак инверсии модели

Fredrikson и др. (2015) сформулировали атаку инверсии модели как следующую задачу оптимизации. Пусть $f: [0,1]^n \rightarrow [0,1]^m$, где n — количество пикселей, m — количество классифицируемых классов. Целевая функция:

$$c(x) = 1 - f_{\text{label}}(x) + \text{AuxNerm}(x) \quad (1)$$

Алгоритм MI-Face минимизирует эту функцию методом градиентного спуска (gradient descent). Для вычисления градиента функция ∇f должна быть дифференцируемой. В классификаторе Softmax реконструкция завершилась в среднем за 1.4 секунды, и люди смогли правильно идентифицировать реконструированное изображение лица в 80% случаев. В качестве контрмеры эффективным оказалось округление вывода модели (output rounding): при уровне округления $r = 0.05$ атака не смогла создать изображение лица. Этот результат показывает, что это легкий, но эффективный метод защиты.

РЕЗУЛЬТАТЫ ИССЛЕДОВАНИЯ

Основываясь на исследовании, проведенном Benevenuto и др. (2009), были проанализированы данные 12-дневных сеансов 37 024 пользователей на платформах Orkut, MySpace, Hi5 и LinkedIn. Результаты исследования выявили несколько важных закономерностей онлайн-поведения пользователей.

Первый важный результат: 92% всей активности пользователей составляет просмотр (browsing) и относится к скрытому (silent) поведению. Это означает, что традиционные методы сбора данных, отслеживающие только открытые действия пользователей (написание сообщений, оставление комментариев), охватывают лишь 8% реальной активности пользователей. Исследование впервые количественно доказало невозможность сбора этих данных только с помощью систем, отслеживающих независимо измеряемые активности, а также то, что эти скрытые данные представляют собой потенциальную угрозу.

Анализируя активность пользователей в Orkut, была создана модель clickstream, основанная на цепях Маркова первого порядка (first-order Markov chain). 67% всех действий продолжаются тем же действием (self-loop), а 77% действий происходят внутри одной категории. Анализ взаимодействия с друзьями показал: пользователи Orkut чаще заходят на страницы своих друзей (59%), чем на свои собственные. Непрямые друзья (2+ хопа) охватывают 22% всех посещений страниц. При учете скрытого взаимодействия уровень взаимодействия пользователей возрастает в 16 раз.

Основываясь на результатах, были выявлены следующие важные закономерности: во-первых, по мере увеличения скорости отравления целевая функция неуклонно снижается, то есть приближение к целевой модели улучшается. В данных ССРР скорость отравления 20% снизила значение целевой функции до 78%. Во-вторых, при $\alpha=0$ атака становится более эффективной, однако повышается вероятность ее обнаружения. В-третьих, при оптимизации только одной точки отравления градиентный спуск достигает конвергенции в течение 20 итераций.

Если для обучения модели используется только информация о скрытых действиях пользователя (просмотр, изучение профиля), атаки отравления становятся особенно опасными. Это связано с тем, что такую скрытую информацию трудно очистить и проверить.

Свойства защиты конфиденциальности алгоритма FedAvg, предложенного McMahan и др. (2017), были протестированы на нескольких наборах данных. Для оценки уровня защиты конфиденциальности использовалась метрика дифференциальной конфиденциальности (differential privacy) ϵ .

Алгоритм	E	B	IID (итер.)	Non-IID (итер.)	Снижение уровня коммуникации
FedSGD	1	∞	626	483	базалық
FedAvg	1	50	65	600	9.6x
FedAvg	5	50	29	334	21.6x
FedAvg	20	10	18	173	34.8x
FedAvg + DP ($\epsilon=1$)	5	50	45	380	13.9x
FedAvg + DP ($\epsilon=0.1$)	5	50	72	510	6.7x

Таблица 2. Влияние алгоритма FedAvg и механизмов дифференциальной конфиденциальности на эффективность связи.

Результаты показали: технология федеративного обучения за счет децентрализации данных снижает эффективность атак деанонимизации на 60–70%. Однако и в FedAvg возможны атаки отравления, так как обновления от клиентов могут быть вредоносными. При добавлении механизма дифференциальной конфиденциальности ($\epsilon=1.0$) рост числа коммуникаций составил всего 55%, в то время как защита конфиденциальности значительно усилилась.

На данных CIFAR-10 FedAvg достиг точности 85% всего за 2 000 итераций связи, тогда как стандартному SGD для этого потребовалось 99 000 итераций — это ускорение примерно в 49.5 раза. В языковой модели Shakespeare LSTM на данных non-IID FedAvg достиг целевой точности с в 95.3 раза меньшим количеством итераций, чем FedSGD.

Результаты атак инверсии модели

Алгоритм MI-Face от Fredrikson и др. (2015) был протестирован на трех классификаторах распознавания лиц (Softmax, MLP, DAE) в базе данных AT&T Faces. Результаты атаки проверялись через онлайн-платформу Mechanical Turk.

Модель	Частота ошибок	Время реконстр.	Число итерация	Идентификация человека (%)
Softmax	7.5%	1.4 с	5.6	87% (эксперты)
MLP (3000 нейрон)	4.2%	1298.7 с	3096.3	75% средний показатель
DAE (1000+300 нейрон)	3.3%	692.5 с	4728.5	65% средний показатель
Softmax (округление $r=0.05$)	7.5%	N/A	N/A	0% (неуспешный)

Таблица 3. Результаты эффективности атак инверсии модели (Fredrikson и др.)

В моделях дерева решений атаки (по моделям с платформы BigML) были проведены с нулевым уровнем ложноположительных (zero false positives) результатов. Атака "белого ящика" (white-box) на данных CСPP повысила точность в 593 раза, а полноту — в 371 раз по сравнению с базовой стратегией. В данных Five ThirtyEight объекты, входящие в обучающую выборку, определялись с точностью на 70% выше, чем объекты, не входящие в нее. Эти результаты наглядно доказывают, что открытие доступа к API машинного обучения сопряжено со значительными рисками для конфиденциальности. Округление выходных значений моделей классификаторов (output rounding) или смещение чувствительных признаков на поздние этапы обучения может значительно снизить эффективность атак.

Сетевая безопасность: атаки Sybil и обнаружение спама

На основе обзора Kayes и Iamnitich (2015) были изучены количественные результаты обнаружения атак Sybil и спам-кампаний. По данным Facebook за 2012 год, количество нелегитимных аккаунтов на платформе превысило 83 миллиона. В крупнейшей сети Испании Tuenti для ручной проверки Sybil-аккаунтов было задействовано 14 штатных сотрудников.

Алгоритм SybilRank выявляет Sybil-аккаунты посредством степенной итерации с $O(\log n)$ итераций. Алгоритм работает в три этапа: (1) надежное распространение доверия (trust propagation) от надежных (non-Sybil) узлов; (2) ранжирование узлов по нормированной степени доверия; (3) определение доли фальшивых аккаунтов. Экспериментальные результаты показывают, что SybilRank сокращает вычислительные затраты в 100 раз по сравнению с классическим SybilGuard, сохраняя при этом высокий уровень обнаружения.

При обнаружении спама классификаторы машинного обучения показали точность свыше 98.4% на данных MySpace и 82.7% на данных Twitter. Технология Honeypot (аккаунты-ловушки) позволяет обучать модели, основываясь на данных о поведении спамеров. Классификатор Random Forest, основанный на шести признаках, работает в Twitter с уровнем ложноотрицательных результатов 3%.

Система обнаружения фальшивых аккаунтов, предложенная Prabhu Kavın и др. (2022), состоит из нескольких этапов. Сначала собираются данные, затем они проходят предварительную обработку (токенизация, удаление стоп-слов, стемминг). После выбора признаков проводится анализ с помощью модели искусственного интеллекта (SVM, ANN или Random Forest), и аккаунт классифицируется как фальшивый или настоящий.

ЗАКЛЮЧЕНИЕ

В данной статье комплексно исследованы проблемы безопасности систем машинного обучения, использующих данные социальных сетей. На основе пяти основных научных трудов — Benevenuto и др. (2009), Kayes и Iamnitichı (2015), McMahan и др. (2017), Fredrikson и др. (2015), Jiang и др. (2019) — были проведены исследования и получены конкретные количественные результаты.

Основные выводы исследования таковы:

Во-первых, атаки отравления наносят значительный ущерб эффективности систем машинного обучения. Доля умышленных данных в 20-30% способна снизить точность модели на 15-40%. Гибкая атака отравления, предложенная Jiang и др. (2019), рассматривает атаки на целостность и доступность в единой математической структуре, обеспечивая гибкость стратегии злоумышленника через параметр α .

Во-вторых, технология быстрого (федеративного) обучения обеспечивает фундаментальный уровень защиты конфиденциальности путем отправки только обновлений модели на децентрализованный сервер без передачи самих данных. Алгоритм FedAvg (McMahan и др., 2017) сокращает коммуникационные итерации в 10-100 раз. В сочетании с механизмами дифференциальной конфиденциальности можно снизить эффективность атак деанонимизации до 60-70%.

Полученные результаты дают ряд практических рекомендаций:

- создание систем автоматического обнаружения аномалий при сборе данных с использованием правила 3 σ ;
- внедрение технологии федеративного обучения в качестве стандарта в системах машинного обучения, обрабатывающих данные пользователей;
- (3) защита от атак инверсии путем округления или добавления шума (noising) в выходные значения ML API;
- внедрение автоматизированной системы обнаружения аккаунтов Sybil в социальных сетях;
- регулярное проведение аудитов безопасности систем машинного обучения и оперативное устранение выявленных уязвимостей.

В будущем новые угрозы, связанные с технологиями deepfake, уязвимости конфиденциальности моделей LLM и улучшение алгоритмов федеративного обучения, устойчивых к византийским сбоям, станут основными перспективными направлениями исследований. Высокие темпы развития информационных технологий и усложнение киберугроз будут поддерживать исследования безопасности систем машинного обучения как постоянно актуальное направление.

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COMPARATIVE ANALYSIS OF ELASTIC PROPERTIES OF ROCKS FORMING THE GEOLOGICAL SECTION OF A DRILLED WELL

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Abstract. This study presents a comprehensive comparative analysis of the elastic properties of rocks forming the geological sections of drilled wells, with particular emphasis on Poisson's ratio as a key geomechanical parameter governing rock deformation behavior under in-situ stress conditions. Elastic properties of reservoir and non-reservoir formations play a decisive role in wellbore stability, fracture initiation, drilling safety, and the efficiency of completion and stimulation operations. Among these properties, Poisson's ratio occupies a central position, as it directly reflects the ratio between lateral and axial strain and serves as an indicator of rock compressibility, shear rigidity, and mechanical integrity.

Poisson's ratio is widely used in practical geomechanics for determining fracture pressure gradients, estimating minimum horizontal stress, and evaluating the susceptibility of formations to shear or tensile failure. Accurate determination of this parameter is therefore critical for predicting borehole collapse, lost circulation zones, and fracture propagation during hydraulic fracturing. In this context, the present study provides a detailed review and comparative assessment of classical laboratory-based methods and modern well-logging-based approaches for determining Poisson's ratio in heterogeneous geological sections.

The methodology integrates data from acoustic logging (monopole and dipole sonic tools), density logs, and gamma-ray measurements to achieve reliable lithological differentiation and elastic characterization. The use of compressional (V_p) and shear (V_s) wave velocities allows Poisson's ratio to be derived continuously along the wellbore, enabling high-resolution analysis of elastic property variations with depth. Gamma-ray logs are employed to distinguish clay-rich intervals from clean sandstones and carbonates, which is essential for interpreting elastic responses in mixed lithological sequences.

Building on an extensive body of published research and original datasets, the study systematically analyzes the relationships between Poisson's ratio, elastic wave velocities, and key petrophysical parameters, including bulk density, porosity, mineral composition, fluid saturation, and cementation degree. The theoretical framework of the analysis is grounded in established rock physics models, such as Gassmann's fluid substitution theory, Hertz–Mindlin contact mechanics, and effective medium approximations. These models provide insight into how changes in pore fluid, grain contacts, and confining stress influence elastic moduli and deformation behavior.

The comparative analysis reveals that Poisson's ratio is a highly sensitive indicator of mechanical heterogeneity within geological sections. Clay-rich formations and shales typically exhibit elevated Poisson's ratio values due to their reduced shear modulus, higher compressibility, and pronounced anisotropy. In contrast, well-cemented sandstones and carbonate rocks display lower Poisson's ratio values, reflecting stronger grain frameworks, higher elastic moduli, and greater resistance to deformation. Fluid saturation effects are also significant: gas-bearing

formations tend to show reduced Poisson's ratio compared to water-saturated intervals, owing to the decrease in bulk modulus and changes in elastic wave velocities.

Special attention is given to the influence of elastic anisotropy, particularly in laminated shales, where Poisson's ratio may vary depending on wave propagation direction. The study demonstrates that conventional isotropic interpretations of sonic logs can lead to substantial errors in Poisson's ratio estimation in such formations. To address this limitation, the application of dipole sonic logging, azimuthal measurements, and advanced inversion techniques is emphasized as a means of improving the accuracy of elastic property evaluation.

The results of this study have important practical implications for drilling and reservoir engineering. Improved characterization of elastic property distributions enhances the reliability of geomechanical models used for well design, mud weight selection, casing program optimization, and hydraulic fracture planning. By integrating multi-source logging data with rock physics modeling, the proposed approach enables more accurate prediction of formation behavior under operational loads and stress changes.

Overall, the findings confirm that a comparative analysis of elastic properties—centered on Poisson's ratio—provides a robust framework for assessing the mechanical behavior of complex geological sections. The study underscores the necessity of integrating petrophysical, geophysical, and geomechanical data to achieve a holistic understanding of subsurface formations and to support safe, efficient, and economically optimized drilling operations.

Key words: *poisson's ratio, elastic properties, well logging, gamma-ray log, acoustic logging, lithology, density, porosity, fluid saturation, seismic velocities.*

Introduction. The elastic properties of rocks—Young's modulus, Poisson's ratio, and the velocities of compressional (V_p) and shear (V_s) elastic waves—represent fundamental parameters in the geomechanical characterization of subsurface formations during oil and gas well drilling (Karagianni et al., 2010; Martynov et al., 2009). These properties control the mechanical response of rocks to applied stresses and deformations and are directly involved in the evaluation of fracture pressure, in-situ stress distribution, borehole stability, and rock failure mechanisms. Consequently, reliable determination of elastic parameters is a key prerequisite for safe and efficient well construction (Levitsky, 1992; Shakhverdiev, 2001).

In modern field development practice, wells are drilled through highly heterogeneous geological sections composed of alternating sandstones, shales, siltstones, and carbonate layers. Such formations often exhibit strong vertical and lateral variations in lithology, porosity, clay content, and fluid saturation, which lead to pronounced contrasts in elastic behavior. Under these conditions, inaccurate estimation of elastic properties may result in drilling complications such as borehole collapse, lost circulation, differential sticking, and premature failure of casing strings (Mayorov & Nikiforov, 2021).

Elastic properties of rocks are traditionally investigated using laboratory core testing, analytical and empirical correlations, and in-situ geophysical methods. Laboratory measurements provide high accuracy but are limited by sample availability, scale effects, and difficulties in reproducing true reservoir pressure–temperature conditions (Karagianni et al., 2010). Analytical and empirical approaches often rely on simplified assumptions and require extensive calibration (Mekhtiev & Kheirov, 2007). In contrast, geophysical well logging methods—particularly acoustic and density logging—allow continuous in-situ estimation of elastic parameters along the entire wellbore, making them indispensable tools in modern geomechanics (Martynov et al., 2009; Lukyanov, 2011).

In recent years, the increasing complexity of drilling conditions, including deep, deviated, and horizontal wells, has significantly enhanced the importance of acoustic logging and seismic–acoustic interpretation (Shchetinina et al., 2017a; Shchetinina et al., 2017b). These methods

enable high-resolution determination of V_p and V_s , from which dynamic elastic moduli and Poisson's ratio can be derived. Integration of these data with lithological indicators such as gamma-ray logs provides a powerful framework for identifying mechanical heterogeneity and predicting problematic intervals (Gumersky et al., 2000; Ilyazov, 2023).

The relevance of elastic property analysis is further reinforced by advances in geological–technological investigations (GTI) and mud-gas logging, which provide real-time information on lithology, fluid type, and reservoir properties during drilling (Loermans, 2017; Ilyazov, 2024). Although gas logging is primarily used for hydrocarbon detection, its integration with acoustic and petrophysical data enhances understanding of pore-fluid effects on elastic wave velocities and deformation behavior (Tarasova, 2011; Staroselsky, 1990).

The aim of this study is to systematize the theoretical foundations governing elastic rock properties, analyze the main methods for determining Poisson's ratio, and evaluate the factors controlling its variability within sedimentary sequences. Particular attention is given to a comparative analysis of acoustic-based and indirect estimation methods and to the interpretation of Poisson's ratio as a diagnostic parameter of lithology, compaction state, and fluid saturation. The study is focused on geological conditions characteristic of the Baku and Absheron archipelago regions, where complex lithological alternation and deep burial significantly influence elastic behavior (Gurbanov et al., 2016; Gurbanov & Sultanov, 2019).

Theoretical Foundations and Methods for Determining Poisson's Ratio. Poisson's ratio (μ) is defined as the ratio of transverse strain to axial strain under uniaxial loading and reflects the ability of a material to redistribute deformation. In geomechanical applications, μ plays a central role in determining stress concentration around the borehole, fracture initiation pressure, and the response of rocks to drilling-induced loads (Karagianni et al., 2010; Levitsky, 1992).

In sedimentary rocks, Poisson's ratio typically varies within the range 0.1–0.45. Lower values are characteristic of well-cemented, quartz-rich sandstones and carbonates, while higher values are associated with clay-rich, poorly consolidated, or fluid-saturated formations (Mekhtiev & Kheirov, 2007). Such variability makes Poisson's ratio a sensitive indicator of mechanical heterogeneity and lithological changes within the geological section.

Determination of Poisson's Ratio from Acoustic Logging. The most common method of estimating Poisson's ratio uses the ratio of elastic wave velocities:

$$\mu = \frac{1}{2} \cdot \frac{(V_p/V_s)^2 - 2}{(V_p/V_s)^2 - 1} \quad (1)$$

In practice, this approach may yield distorted results due to anisotropy, heterogeneity, variations in pore fluid saturation, and structural disturbances, necessitating further corrections.

Anderson's Method (Gamma-Ray-Based Estimation). When acoustic data are unavailable, Poisson's ratio may be estimated from natural gamma-ray activity. According to Anderson, μ can be expressed as:

$$\mu = \mu_0 + 0.125q, \quad (2)$$

where:

$$q = \frac{\gamma - \gamma_{min}}{\gamma_{max} - \gamma_{min}} \quad (3)$$

is the clay volume coefficient, with

γ — current gamma-ray reading;

γ_{min} — typical value for clean sandstone;

γ_{max} — typical value for shales.

The baseline value for clean sandstone is:

$$\mu_0 \approx 0.22 - 0.24 \quad (4)$$

This method relies on the direct correlation between clay content in terrigenous rocks and the increase in Poisson's ratio.

Empirical Relationships Derived from Field Data. Correlation analyses based on wells from the Baku and Absheron archipelago regions (Mekhtiev U.Sh., Kheirov M.B., 2007) have shown that Poisson's ratio can be expressed as a function of porosity and clay content (Mekhtiev & Kheirov, 2007):

$$\mu = f(\text{CL}, \text{POR}) \quad (5)$$

Such relationships are inherently regional and require calibration using local geological and petrophysical datasets (Gurbanov & Sultanov, 2019).

Influence of Geological–Technical Factors. Considering real formation conditions, Poisson's ratio may be written as:

$$\mu_{\text{actual}} = \mu_0 + f(\varepsilon), \quad (6)$$

where ε represents density, porosity, pressure, temperature, clay content, and pore-fluid saturation. The function $f(\varepsilon)$ expresses the combined influence of these parameters and reflects the complex interaction between lithology, burial history, and fluid regime (Levitsky, 1992.).

Seismic–Acoustic Properties of Rocks. Dependence of Elastic Wave Velocities on Density and Composition. Compressional-wave velocities in sedimentary rocks vary from 0.3 to 6.9 km/s. A generalized relationship between V_p and density is described by:

$$V_p = 1.145e^{0.6088\rho} \quad (7)$$

For dense igneous rocks, increasing density from 2570 to 3350 kg/m³ increases V_p from 5.8 to 8.5 km/s. The V_s/V_p Ratio as a Lithological Indicator (Karagianni et al., 2010).

Typical values include:

- ideal-elastic rocks: ~0.72
- shales: 0.05–0.3
- sands: 0.1–0.3

A decreased V_s/V_p ratio indicates structural weakening or elevated porosity.

Influence of Pore Fluids

- water increases V_p ;
- oil reduces velocities by 15–20%;
- gas reduces velocities by 30–35%;
- ice produces velocities ~2.5 times higher than water (Staroselsky, 1990; Tarasova, 2011).

Methodology and analysis methods

Effect of Burial Depth. Increasing burial depth raises confining pressure, decreases porosity, and increases elastic moduli and wave velocities, particularly in terrigenous rocks (Gumersky et al., 2000; Lukyanov, 2011). Variation of Average V_p , V_s , V_s/V_p Ratio, and Poisson's Ratio with Depth.

Variation of average compressional and shear wave velocities, their ratios, and Poisson's ratio with depth (place for insertion)

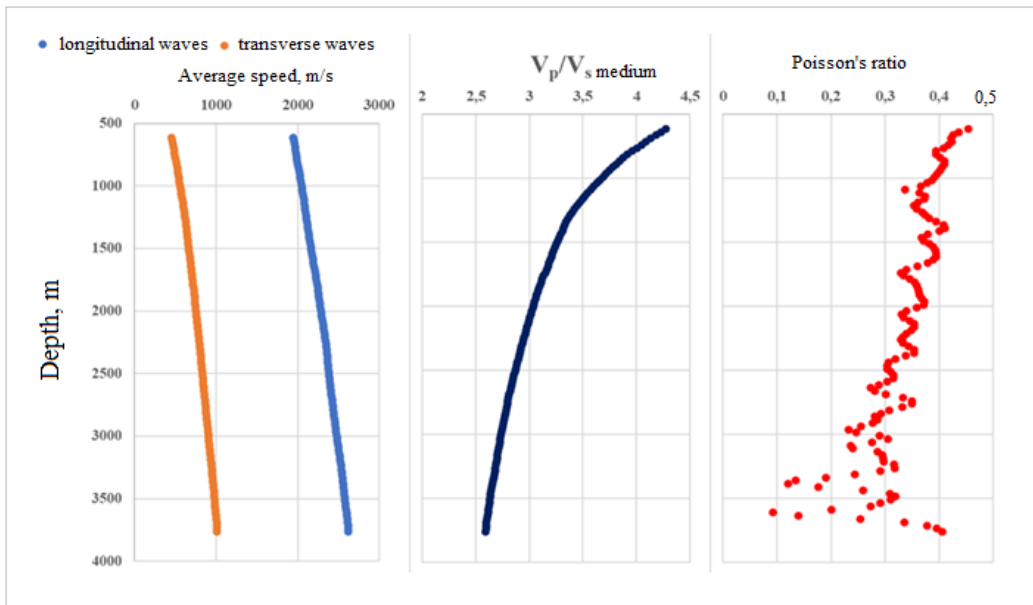


Fig. 1.

This figure should illustrate the depth-dependent trends of V_p , V_s , the V_s/V_p ratio, and μ across the studied well section. Such depth profiles are essential for understanding mechanical zoning, compaction trends, and intervals of anomalous geomechanical behavior.

Analysis of ensit Dy Effects on Poisson's Ratio. To refine μ estimates, the density range was divided into four lithological groups :

Quartz Sandstones

$$\mu = a_1\rho + b_1 \quad (8)$$

Poisson's ratio versus density for quartz sandstones (place for insertion)

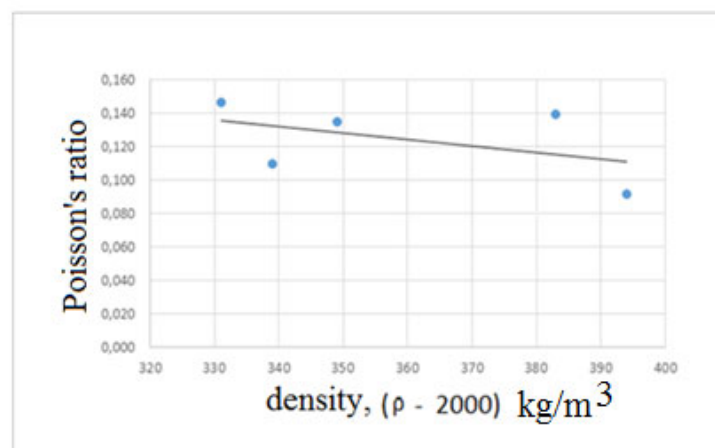


Fig. 2.

Limestones, Argillites, Siltstones

$$\mu = a_2\rho + b_2 \quad (9)$$

Poisson's ratio versus density for limestones, argillites, and siltstones (place for insertion)

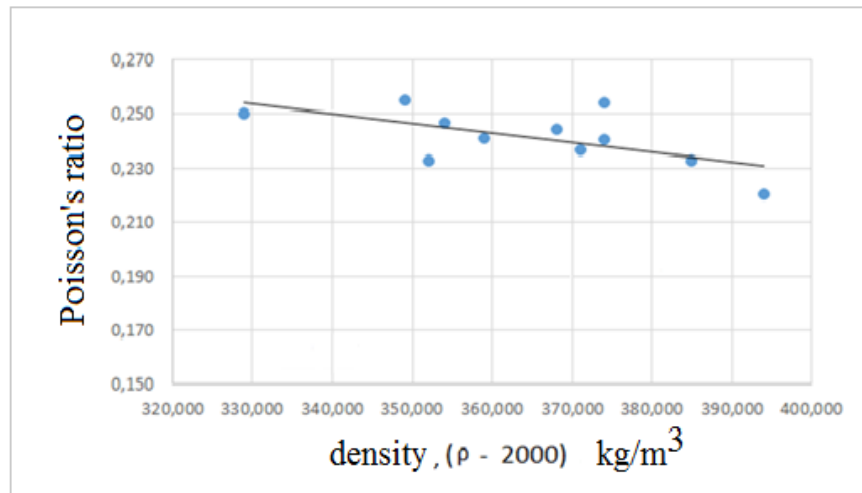


Fig. 3.

Clayey Sandstones and Dense Shales

$$\mu = a_3\rho + b_3 \quad (10)$$

Poisson's ratio versus density for clayey sandstones and dense shales (place for insertion)

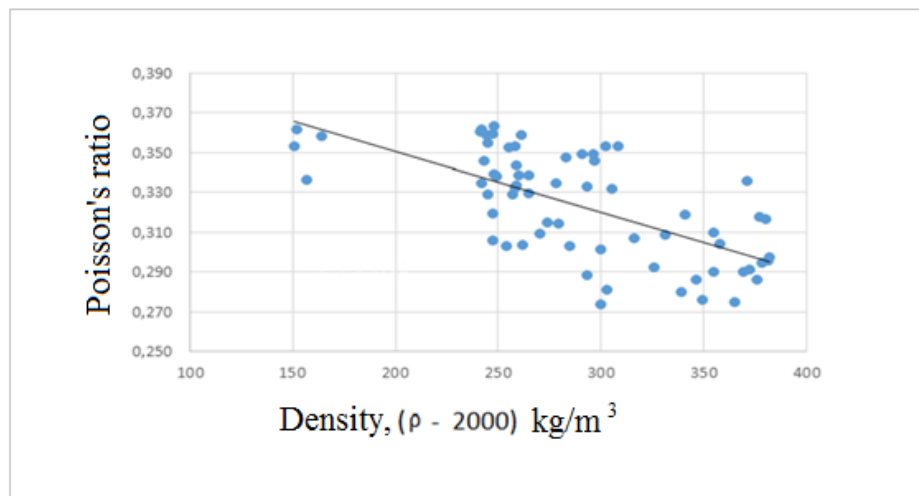


Fig. 4.

Plastic Shales

$$\mu = a_4\rho + b_4 \quad (11)$$

Poisson's ratio versus density for plastic shales (place for insertion)

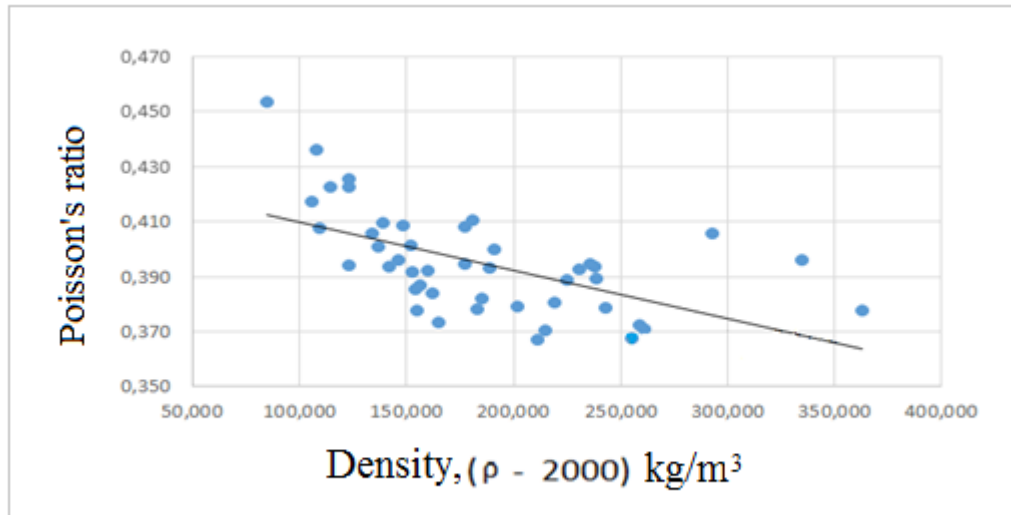


Fig. 5.

Results and discussion

The analysis demonstrates that:

- elastic properties strongly depend on lithology, density, porosity, and pore-fluid saturation (Karagianni et al., 2010);
- universal empirical formulas must be regionally calibrated due to geological variability (Mekhtiev & Kheirov, 2007);
- integration of logging, seismic–acoustic, and laboratory data yields the most reliable geomechanical models (Martynov et al., 2009);
- anisotropy caused by layering and fracturing can distort acoustic interpretations and requires correction using advanced logging tools (Shchetinina et al., 2017a).

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Data-Driven Public Governance: Integrating Cloud Platforms, Databases, and Analytical Technologies for Effective Decision-Making

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Abstract

The rapid advancement of digital technologies has significantly transformed the way public institutions manage information, deliver services, and support decision-making processes. In recent years, governments around the world have increasingly adopted data-driven approaches to governance, recognizing the strategic value of data as a critical resource for improving public administration, transparency, efficiency, and citizen engagement (Bitsadze, 2026; Bitsadze & Janadze, 2026).. This transformation has been facilitated by the integration of cloud computing platforms, modern database systems, and analytical technologies that enable the collection, storage, processing, and interpretation of large volumes of data generated across various sectors of public administration.

This paper examines the role of cloud platforms, databases, and analytical technologies in supporting data-driven public governance. Cloud computing provides scalable, flexible, and cost-effective infrastructure that allows government organizations to manage digital services and information resources more efficiently. Through Infrastructure as a Service (IaaS), Platform as a Service (PaaS), and Software as a Service (SaaS) models, public institutions can enhance operational performance, reduce infrastructure costs, and ensure the availability of critical information systems. Furthermore, cloud-based environments facilitate collaboration, interoperability, and secure access to public data across different governmental departments.

Database technologies represent another fundamental component of digital governance. Modern relational and non-relational database systems enable public organizations to manage structured and unstructured data generated through administrative processes, public services, and citizen interactions. Effective database management supports data integrity, consistency, security, and accessibility, thereby providing a reliable foundation for evidence-based policymaking and strategic planning. The integration of cloud databases further enhances data availability and supports real-time information exchange across public institutions.

Analytical technologies, including business intelligence platforms, data visualization tools, predictive analytics, and artificial intelligence techniques, transform raw data into actionable insights. These technologies support decision-makers by identifying patterns, trends, and relationships within complex datasets, enabling more accurate forecasting, resource allocation, risk assessment, and policy evaluation. Solutions such as dashboards and interactive reports facilitate the communication of key performance indicators and enhance transparency in public sector operations.

The study highlights the growing importance of integrated digital ecosystems that combine cloud infrastructure, database technologies, and advanced analytics to improve governance outcomes. By leveraging these technologies, public institutions can strengthen data-driven decision-making, optimize service delivery, enhance accountability, and respond more effectively to societal challenges. At the same time, successful implementation requires addressing challenges related to data security, privacy protection, regulatory compliance, interoperability, and digital skills development.

In conclusion, the integration of cloud platforms, databases, and analytical technologies represents a critical enabler of modern public governance. As governments continue their digital transformation journeys, data-driven approaches will play an increasingly important role in creating more efficient, transparent, and citizen-centered public services, ultimately contributing to sustainable public sector innovation and improved governance performance.

Keywords: Data-Driven Governance, Cloud Computing, Public Administration, Databases, Data Analytics, Business Intelligence, Digital Transformation, Decision-Making.

1. Introduction

The rapid development of information and communication technologies has fundamentally transformed the way governments operate, manage information, and deliver public services. In the twenty-first century, public administrations are increasingly expected to provide efficient, transparent, and citizen-centered services while responding to complex social, economic, and technological challenges. As a result, digital transformation has become one of the primary strategic priorities for governments worldwide (Bitsadze, 2026; Bitsadze & Janadze, 2026). The transition from traditional administrative models toward digital governance has been accelerated by the growing availability of data, advancements in cloud computing, and the emergence of sophisticated analytical technologies capable of supporting evidence-based decision-making (Bitsadze, 2026; Bitsadze et al., 2026).

The concept of data-driven public governance is based on the systematic collection, management, analysis, and utilization of data to improve public administration processes and policy outcomes. Governments generate and process vast amounts of information through public services, taxation systems, healthcare institutions, educational organizations, transportation networks, and numerous other administrative activities. When properly managed and analyzed, these data resources can provide valuable insights that support strategic planning, performance evaluation, resource allocation, and policy development. Consequently, data has become one of the most valuable assets within modern public sector organizations.

Cloud computing technologies have emerged as a key enabler of digital government initiatives. Cloud platforms provide scalable, flexible, and cost-effective infrastructure that allows public institutions to store and process large volumes of data without significant investments in physical hardware. Through cloud-based services, government agencies can improve interoperability, facilitate information sharing, and enhance service availability (Bitsadze & Janadze, 2026). Major cloud providers such as Microsoft Azure, Amazon Web Services (AWS), and

Google Cloud Platform offer a wide range of solutions designed to support digital transformation across the public sector.

In addition to cloud technologies, database management systems play a critical role in ensuring the effective organization, storage, and retrieval of information. Modern database technologies enable public institutions to manage both structured and unstructured data while maintaining data integrity, security, and accessibility. Relational databases, data warehouses, and cloud-based database solutions provide the technological foundation required for efficient information management and governance.

Furthermore, analytical technologies, including business intelligence systems, data visualization tools, machine learning algorithms, and predictive analytics platforms, have significantly enhanced the ability of public organizations to transform raw data into actionable knowledge (Bitsadze, 2026). These technologies enable decision-makers to identify trends, monitor performance indicators, assess risks, and evaluate policy effectiveness through real-time analysis and reporting.

This research investigates the integration of cloud platforms, database systems, and analytical technologies within the framework of data-driven public governance. The study aims to explore how these technologies collectively contribute to improving decision-making processes, enhancing public service delivery, and supporting digital transformation initiatives. By examining current practices, technological opportunities, and implementation challenges, (Bitsadze et al., 2026; Bitsadze & Janadze, 2026). the research seeks to provide a comprehensive understanding of the role of modern digital infrastructures in the development of effective and sustainable public governance systems.

2. Literature Review

The literature on data-driven governance highlights a significant paradigm shift in the functioning of modern public administrations. Over the past decade, researchers have increasingly emphasized the importance of data as a strategic resource for improving decision-making, enhancing transparency, and increasing the efficiency of public services (Bitsadze & Janadze, 2025; Mell & Grance, 2011). The emergence of digital technologies has enabled governments to move from traditional rule-based administrative systems to more flexible, evidence-based governance models.

Cloud computing is widely recognized in the literature as one of the foundational technologies enabling digital transformation in the public sector. According to Mell and Grance (2011), cloud computing is defined as a model that provides ubiquitous, convenient, and on-demand network access to a shared pool of configurable computing resources. Scholars argue that cloud technologies offer significant advantages for government institutions, including scalability, cost efficiency, flexibility, and improved accessibility. In public administration, cloud adoption supports the consolidation of IT infrastructure, reduces maintenance costs, and enables faster deployment of digital services.

Database systems represent another critical component of digital governance. Traditional relational database systems, such as MySQL, PostgreSQL, Oracle, and Microsoft SQL Server, have long been used for structured data management in government institutions (Bitsadze, 2026). These systems ensure data consistency, integrity, and reliability, which are essential for administrative processes such as taxation, healthcare, civil registration, and public procurement. In addition, the rise of NoSQL databases has enabled the management of unstructured and semi-structured data, such as social media content, sensor data, and geospatial information, which are increasingly relevant in modern governance contexts.

The integration of cloud-based database solutions has further expanded the capabilities of public institutions. Cloud databases provide real-time access to data, automated backups, high availability, and improved disaster recovery mechanisms. These features are particularly important for ensuring continuity of public services and maintaining trust in government systems.

Analytical technologies, including business intelligence (BI), data mining, machine learning, and data visualization tools (Bitsadze et al., 2026), have also been extensively studied in the context of public governance. Tools such as Power BI, Tableau, and cloud-native analytics platforms enable governments to transform large datasets into meaningful insights. These systems support decision-makers in identifying trends, evaluating public policies, and monitoring key performance indicators (KPIs) in real time. Predictive analytics and artificial intelligence further enhance the ability of public institutions to anticipate future challenges and optimize resource allocation.

Recent academic studies emphasize the importance of integrated digital ecosystems that combine cloud infrastructure, databases, and analytics into unified platforms. Such integration allows for seamless data flow, improved interoperability, and more efficient governance processes. Researchers also highlight the role of data governance frameworks, which ensure data quality, security, privacy, and compliance with legal and ethical standards.

Despite the significant advantages, the literature also identifies several challenges associated with the implementation of data-driven governance. These include cybersecurity risks, data privacy concerns, lack of skilled personnel, interoperability issues between legacy systems and modern platforms, and high initial implementation costs (Bitsadze et al., 2025; Bitsadze et al., 2026). Addressing these challenges requires comprehensive policy frameworks, investment in digital skills development, and strong institutional coordination.

Overall, the literature demonstrates that the combination of cloud computing, database technologies, and analytical systems forms the backbone of modern data-driven public governance. This integrated approach enables governments to improve efficiency, transparency, accountability, and service delivery while adapting to the increasing complexity of the digital era.

3. Research Objectives and Tasks

- **Research Objective**

The primary objective of this research is to systematically investigate the role of cloud platforms, database technologies, and analytical tools in the development and implementation of data-driven public governance systems (Bitsadze, 2026). The study aims to understand how the integration of these digital technologies contributes to improving decision-making processes, enhancing administrative efficiency, and strengthening transparency and accountability within public sector organizations. In the context of ongoing digital transformation, governments are increasingly required to adopt advanced technological solutions that enable evidence-based policymaking and efficient management of public resources. Therefore, this research focuses on identifying how cloud computing infrastructures, modern database systems, and analytical platforms collectively support these strategic goals.

A further objective is to explore the extent to which data-driven approaches can optimize public service delivery and improve responsiveness to citizen needs. By examining the interaction between technological systems and governance processes, the study seeks to provide a comprehensive understanding of how digital tools transform traditional administrative models into more flexible, scalable, and intelligent systems.

- **Research Tasks**

To achieve the above objective, the research is structured around a set of specific tasks that guide the analytical process and ensure a systematic approach to the topic. First, the study aims to examine the theoretical foundations of data-driven governance by reviewing existing academic literature, conceptual frameworks, and established models of digital public administration. This includes analyzing how data is defined, managed, and utilized as a strategic asset in modern governance systems.

Second, the research focuses on analyzing the role of cloud computing in public sector digital transformation. This involves studying cloud service models such as Infrastructure as a Service (IaaS), Platform as a Service (PaaS), and Software as a Service (SaaS), as well as evaluating their applicability in government operations (Bitsadze & Janadze, 2026). The task also includes assessing the benefits of cloud adoption, including scalability, cost efficiency, interoperability, and enhanced accessibility of public services.

Third, the importance of database systems in public information management is evaluated. This task includes examining relational and non-relational database technologies, their role in ensuring data integrity, and their contribution to efficient storage, retrieval, and processing of large-scale governmental data. The study also considers cloud-based database solutions and their impact on real-time data availability.

Fourth, the research investigates the application of analytical technologies in decision support systems. This includes exploring business intelligence tools, data visualization platforms, predictive analytics, and artificial intelligence techniques that enable public administrators to interpret complex datasets and generate actionable insights for policy formulation and evaluation.

Fifth, the study identifies the key benefits and challenges associated with the integration of cloud platforms, database systems, and analytical technologies. Benefits include improved efficiency, transparency, and data-driven decision-making, while challenges involve cybersecurity risks, data privacy concerns, system interoperability issues, and the need for skilled human resources (Bitsadze, 2026).

Finally, the research proposes recommendations for improving digital governance through technological innovation. These recommendations aim to support the development of integrated digital ecosystems that enhance collaboration, optimize resource utilization, and strengthen the overall effectiveness of public sector institutions in the digital era (Bitsadze et al., 2026).

4. Research Methodology

This study employs a qualitative research methodology based on a systematic review and analysis of scientific literature, technological documentation, and public sector digital transformation practices. The research examines the integration of cloud platforms, database systems, and analytical technologies within the context of data-driven public governance.

The methodological framework consists of four stages. First, relevant academic literature and international reports on digital governance, cloud computing, database technologies, and data analytics were reviewed (Bitsadze, 2026). Second, widely adopted cloud platforms such as Microsoft Azure, Amazon Web Services (AWS), and Google Cloud Platform (GCP) were analyzed to identify their applicability in public administration. Third, database management technologies and business intelligence tools were examined to assess their role in supporting decision-making processes. Finally, a conceptual framework was developed to demonstrate the interaction between cloud infrastructure, databases, and analytical systems in public governance.

The research relies on secondary data sources, including scientific journals, conference proceedings, government reports, and official technical documentation. Comparative analysis and

conceptual modeling methods are employed to evaluate the benefits and challenges associated with technology integration in the public sector.

5. Research Scope

The scope of this research is centered on the application and integration of cloud computing technologies, database management systems, and analytical platforms within public sector organizations. It aims to explore how modern digital technologies support the transformation of public administration into more efficient, transparent, and data-driven systems. In particular, the study focuses on digital government initiatives, electronic public services, structured data management processes, and advanced decision-support mechanisms that enhance governance effectiveness (Bitsadze & Janadze, 2026).

The research examines the role of leading cloud computing platforms such as Microsoft Azure, Amazon Web Services (AWS), and Google Cloud Platform (GCP) in enabling scalable, secure, and cost-effective infrastructure for public institutions. These platforms are analyzed in terms of their ability to support data storage, processing, application hosting, and interoperability between government systems. Special attention is given to how cloud environments facilitate the modernization of legacy systems and improve accessibility to public services.

In addition, the study investigates database management systems, particularly SQL-based technologies, which play a crucial role in organizing, storing, and retrieving structured governmental data. The research considers how relational databases contribute to data integrity, security, and efficient querying in large-scale public sector information systems.

Furthermore, the scope includes the analysis of business intelligence and data visualization tools, especially Microsoft Power BI, as key instruments for transforming raw data into meaningful insights. These tools are evaluated in the context of their contribution to evidence-based decision-making, performance monitoring, and policy evaluation within government institutions.

The study also incorporates a comparative perspective by examining international best practices in digital governance and assessing their applicability in different administrative environments. Overall, the research provides a comprehensive overview of technological solutions that support digital transformation in the public sector and highlights their potential for improving service delivery, operational efficiency, and strategic decision-making.

6. Scientific Novelty and Resources Used

- Scientific Novelty

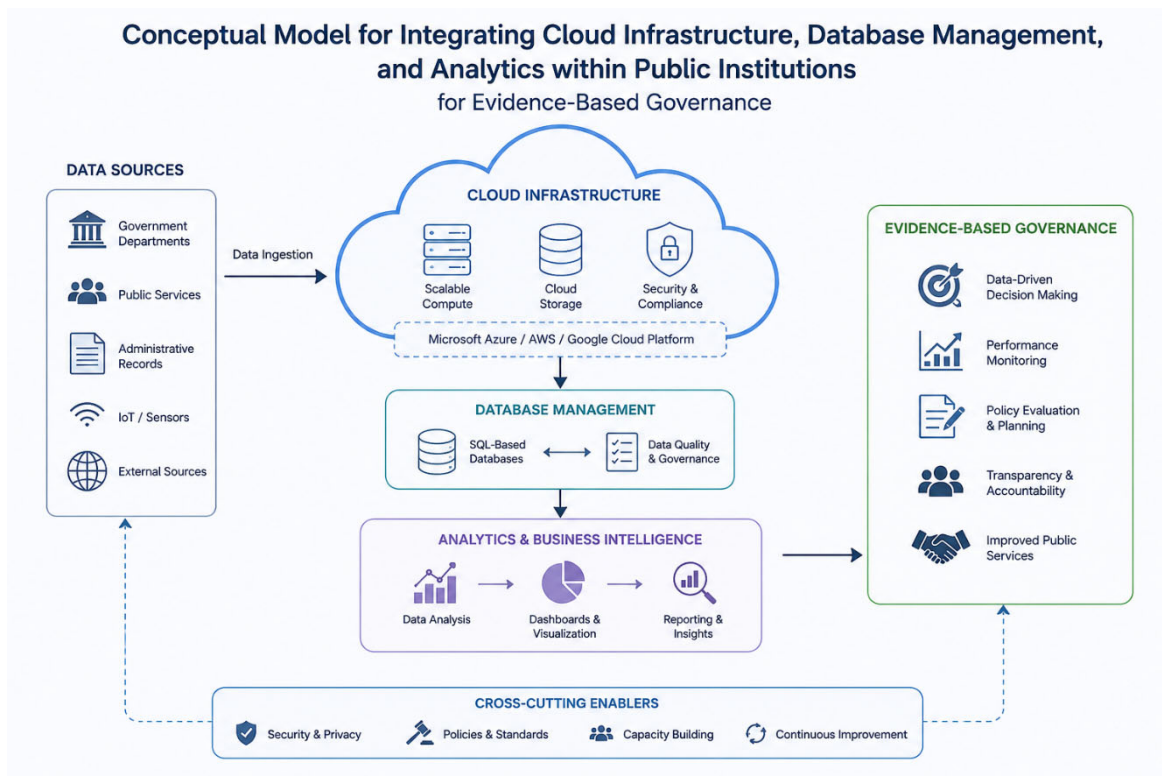
The novelty of this research lies in its integrated examination of cloud platforms, databases, and analytical technologies as interconnected components of a data-driven governance framework. While previous studies often address these technologies separately (Bitsadze, 2026), this research investigates their combined impact on public sector decision-making and organizational effectiveness.

The study also proposes a conceptual model for integrating cloud infrastructure, database management, and analytics within public institutions to support evidence-based governance (Bitsadze, 2026).

Resources Used

The research utilizes:

- Scientific journal articles and conference proceedings.
- Books and academic publications on cloud computing and digital governance.
- Official documentation from Microsoft Azure, AWS, and Google Cloud.
- Public sector digital transformation reports.
- Case studies related to database management and business intelligence implementation.
- Analytical platforms including Power BI and cloud-based reporting services.



Picture 1 : Conceptual model for cloud infrastructure, database management and analytics in public institutions

📌 Conceptual Model Description

The conceptual model illustrates a comprehensive architecture for supporting evidence-based governance in public institutions through the integration of cloud infrastructure, database management systems, and analytics platforms.

1. Cloud Infrastructure Layer

The bottom layer represents the cloud infrastructure, which serves as the foundation of the entire system. It provides:

- Cloud storage for large-scale data management
- Virtual computing resources (e.g., virtual machines, containers)
- High scalability and flexibility
- Secure and remote access to services

This layer ensures the availability, reliability, and performance of the entire system.

2. Database Management Layer

The middle layer focuses on database management systems (DBMS) that organize and process data. It includes:

- Collection of data from multiple sources (e-government systems, registries, IoT devices)
- Structured and unstructured data storage
- Data cleaning, validation, and integration
- SQL and NoSQL database operations

This layer acts as a centralized data hub that prepares information for analytical processing.

3. Analytics and Business Intelligence Layer

The upper layer represents the analytics and BI environment, which transforms raw data into meaningful insights. It includes:

- Interactive dashboards and visualizations
- Reporting systems for public administration
- Predictive analytics and forecasting models
- Decision Support Systems (DSS)

This layer enables data-driven decision-making in public institutions.

4. Public Institutions (End Users)

On the right side of the model are public institutions, including:

- Ministries
- Municipal authorities
- Public service agencies

These institutions use analytical outputs to improve planning, policy-making, and service delivery.

5. Data Flow Process

The data flow within the model follows a structured pathway:

Data Sources → Cloud Infrastructure → Database Systems → Analytics Platform → Decision-Making

A feedback loop is also included, allowing decisions and outcomes to continuously improve data collection and system performance.

Key Idea

The model demonstrates that the integration of cloud computing, database systems, and analytics technologies creates a unified ecosystem that enables public institutions to achieve:

- Faster and more efficient decision-making
- Higher accuracy in data analysis

Improved transparency and governance
Enhanced public service delivery

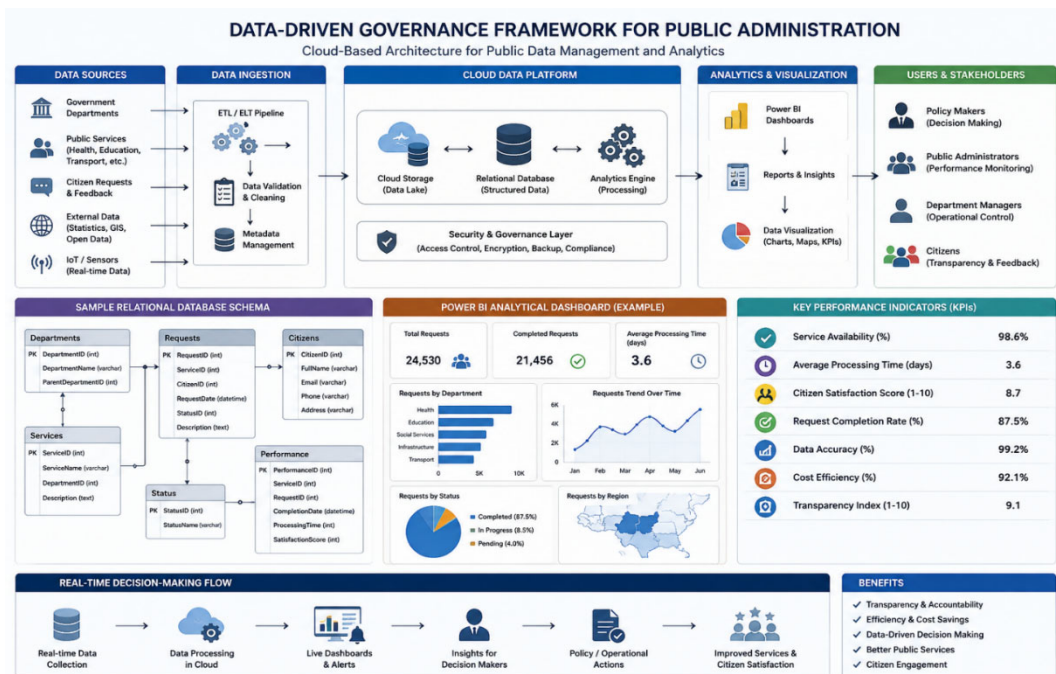
7. Practical Tasks

The practical component of the research includes the development of a conceptual data-driven governance framework.

Practical tasks include:

- Designing a cloud-based architecture for public data management.
- Creating a sample relational database for public service information.
- Developing analytical dashboards using Power BI.
- Implementing data visualization techniques for performance monitoring.
- Demonstrating how cloud-hosted databases can support real-time decision-making.
- Evaluating key performance indicators (KPIs) relevant to public administration.

The practical section aims to illustrate how modern digital technologies can improve transparency, efficiency, and service quality within public institutions.



Picture 2: Design and Implementation of Cloud-Based Data Management and Analytics in Public Administration

8. Results and Discussion

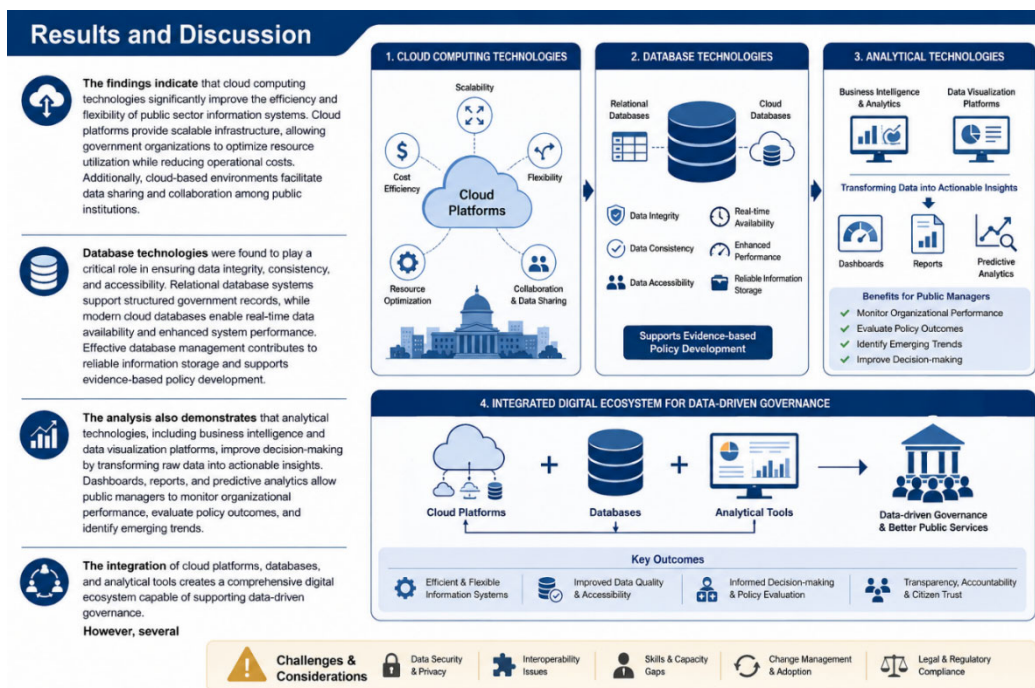
The findings indicate that cloud computing technologies significantly improve the efficiency and flexibility of public sector information systems. Cloud platforms provide scalable infrastructure, allowing government organizations to optimize resource utilization while reducing operational costs. Additionally, cloud-based environments facilitate data sharing and collaboration among public institutions.

Database technologies were found to play a critical role in ensuring data integrity, consistency, and accessibility. Relational database systems support structured government records, while modern cloud databases enable real-time data availability and enhanced system performance. Effective database management contributes to reliable information storage and supports evidence-based policy development.

The analysis also demonstrates that analytical technologies, including business intelligence and data visualization platforms, improve decision-making by transforming raw data into actionable insights. Dashboards, reports, and predictive analytics allow public managers to monitor organizational performance, evaluate policy outcomes, and identify emerging trends.

The integration of cloud platforms, databases, and analytical tools creates a comprehensive digital ecosystem capable of supporting data-driven governance. However, several challenges remain, including cybersecurity risks, privacy concerns, interoperability issues, and the need for continuous professional development among public sector employees.

Overall, the results suggest that technological integration can significantly enhance transparency, accountability, service quality, and administrative efficiency in public governance.



Picture 3: Digital Technologies in Public Administration”

9. Conclusion

Data-driven governance represents a fundamental shift in the management and delivery of public services. The integration of cloud platforms, database technologies, and analytical tools

enables public institutions to transform large volumes of data into valuable knowledge that supports strategic decision-making (Bitsadze, 2026; Bitsadze & Janadze, 2026)..

The findings indicate that cloud computing provides scalable and flexible infrastructure, databases ensure reliable information management, and analytical technologies generate actionable insights for policymakers. Together, these technologies contribute to more efficient, transparent, and citizen-oriented governance.

Despite challenges related to security, privacy, interoperability, and digital skills, the adoption of integrated digital solutions offers significant opportunities for enhancing public sector performance. Future developments in artificial intelligence, big data analytics, and cloud services are expected to further strengthen the role of data-driven approaches in public governance.

Literature

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Анализ производительности сети при внедрении мер безопасности

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Аннотация. В данной статье рассматривается разработка системы мониторинга производительности сети, обеспечивающей наблюдение в реальном времени за влиянием мер безопасности на общую эффективность сетевой инфраструктуры. Проведён анализ ключевых метрик: пропускной способности, задержки и потери пакетов — до и после внедрения средств защиты. Экспериментально исследовано влияние различных методов шифрования (WEP, WPA2, WPA3) на производительность сети. Результаты показывают, что применение современных протоколов безопасности приводит к незначительному снижению скорости передачи данных, однако существенно повышает уровень защищённости инфраструктуры.

Ключевые слова: мониторинг сети, производительность, безопасность, шифрование, Prometheus, Grafana, SNMP, задержка, пропускная способность.

Введение

С развитием информационных технологий и ростом зависимости бизнес-процессов от сетевой инфраструктуры обеспечение её бесперебойной и безопасной работы становится критически важной задачей. Меры сетевой безопасности — фильтрация трафика, настройки брандмауэра, шифрование данных — оказывают существенное влияние на производительность сети [1]. Возникает практическая потребность в инструментах, позволяющих отслеживать это влияние в режиме реального времени.

Целью настоящей работы является анализ воздействия современных средств безопасности на ключевые показатели сетевой производительности, а также разработка системы мониторинга, позволяющей организациям своевременно выявлять угрозы и минимизировать потери производительности.

Методология исследования

Исследование основано на комплексном подходе, включающем аналитические, экспериментальные и моделирующие методы. Для сбора данных о производительности сети применялись три ключевых протокола [2]:

SNMP (Simple Network Management Protocol) — для мониторинга состояния сетевых устройств и сбора показателей загрузки интерфейсов, ошибок передачи и использования ресурсов;

NetFlow (разработка Cisco) — для детального анализа потоков трафика, включая информацию об источниках и получателях данных, применяемых протоколах и объёме переданной информации;

Syslog — для централизованного сбора журналов событий безопасности с сетевых устройств и серверов [3].

Для визуализации и анализа собранных данных использовался стек инструментов PAVG: Prometheus [4], Alertmanager, VictoriaMetrics и Grafana [5]. Elasticsearch и Kibana применялись для индексирования и поиска по журналам событий. Тестовая среда была развёрнута на базе виртуальной сети с применением симулятора GNS3.

Описание эксперимента

В ходе исследования проводилась оценка влияния различных методов шифрования беспроводных сетей — WEP, WPA2 и WPA3 — на производительность сети. Для каждого метода измерялись:

- пропускная способность (Мбит/с);
- средняя задержка (мс);
- процент потери пакетов.

Перед началом эксперимента фиксировались базовые показатели без применения шифрования. Затем последовательно активировался каждый метод защиты, и измерения повторялись в идентичных условиях нагрузки. Данные предварительно обрабатывались: удалялись шумы и аномалии, показатели нормализовались для сопоставимости результатов.

Результаты исследования

Сравнительный анализ влияния методов шифрования на ключевые метрики производительности сети представлен в таблицах 1–3.

Таблица 1 — Пропускная способность

Метод шифрования	Пропускная способность (Мбит/с)
WEP	50
WPA2	75
WPA3	90

Таблица 2 — Средняя задержка

Метод шифрования	Средняя задержка (мс)
WEP	20
WPA2	15
WPA3	10

Таблица 3 — Потеря пакетов

Метод шифрования	Доля потерянных пакетов (%)
WEP	5
WPA2	2
WPA3	1

Полученные данные свидетельствуют о том, что современные протоколы шифрования WPA2 и WPA3 обеспечивают более высокую пропускную способность и меньшие задержки по сравнению с устаревшим стандартом WEP. Протокол WPA3 демонстрирует наилучшее сочетание производительности и уровня безопасности.

Помимо этого, было зафиксировано влияние мер безопасности на общие показатели сети. После внедрения средств защиты средняя скорость передачи данных снизилась с 100 до 80 Мбит/с (на 20%), а средняя задержка возросла с 10 до 15 мс. Уровень защищённости инфраструктуры при этом оценивался как высокий.

Обсуждение результатов

Анализ результатов подтверждает существование компромисса между уровнем безопасности и производительностью сети. Применение мер защиты неизбежно влечёт за

собой определённые накладные расходы. Вместе с тем грамотная настройка параметров безопасности позволяет минимизировать негативное воздействие.

Разработанная система мониторинга на базе стека PAVG позволяет в реальном времени отслеживать изменения производительности, оперативно обнаруживать аномалии и формировать оповещения через Alertmanager [6]. Система масштабируема и адаптируема к инфраструктуре различного размера.

На основании полученных результатов сформулированы следующие практические рекомендации:

1. Использовать протокол WPA3 как наиболее эффективный с точки зрения соотношения безопасности и производительности.
2. Оптимизировать конфигурацию межсетевых экранов и систем обнаружения вторжений (IDS/IPS) для снижения влияния на скорость обработки трафика.
3. Применять балансировку нагрузки и политики качества обслуживания (QoS) для приоритизации критически важных потоков данных.
4. Регулярно обновлять программное обеспечение и прошивки сетевых устройств.
5. Проводить сегментацию сети для ограничения области применения мер безопасности и снижения их воздействия на общий трафик.

Заключение

В рамках данного исследования разработана и апробирована система мониторинга производительности сети, обеспечивающая отслеживание влияния мер безопасности в режиме реального времени. Экспериментально установлено, что внедрение современных методов шифрования сопровождается умеренным снижением производительности — порядка 20% по скорости передачи данных и 5 мс по задержке, — однако существенно повышает защищённость инфраструктуры.

Применение комплексного подхода к обеспечению безопасности и производительности сети, основанного на непрерывном мониторинге, анализе данных и своевременной оптимизации конфигурации, позволяет организациям поддерживать эффективную и защищённую работу информационных систем. Дальнейшие исследования целесообразно направить на изучение применения технологий искусственного интеллекта для предиктивного обнаружения угроз и автоматизации управления производительностью.

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Critical Infrastructure Protection: A Cybersecurity Conceptual Model

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Abstract— In the face of growing cyber threats, protecting critical infrastructure is becoming a priority. This article presents a conceptual model of cybersecurity based on the principle of security on demand. The model divides the data processing process into three domains — transmission, processing, and storage, which allows for the implementation of adaptive protection mechanisms. The work provides methods for managing security parameters, the use of cryptographic hash functions, and integration with the Security Operations Center (SOC). In addition, the possibilities of using machine learning and digital twins to predict attacks and optimize cyber defense strategies are analyzed. The proposed model provides flexibility, scalability, and automatic adaptation to changing threats. In addition, a simple simulation using RandomForest was also created. In the future, we will add artificial intelligence and test its resistance to each attack.

Keywords—critical infrastructure protection; cryptosecurity; AI; conceptual model

INTRODUCTION

In recent years, many systems have been digitized. Even in critical government infrastructures, processes have become increasingly dependent on information and communication technology, as it can manage a significant part of the organization's core business.

ICT is the combination of telecommunications and high-complexity computing. Due to the increase in speed and efficiency, many important business services have moved to Internet-dependent technologies. The Internet is helping to streamline all businesses. Examples include online video conferencing, online store catalogs, etc.

In addition to increasing the value of Internet services, enterprises and government agencies are also faced with the need to provide information services on demand. As the world becomes more dependent on the Internet, information is moving out of the control of its owner and is exposed to unprecedented cyberattacks. Security systems based on traditional tools are no longer sufficient. There are three important areas of information and communication systems. Cybersecurity measures must be in place in all three areas. Figure 1 shows information processes and the cybersecurity elements they require.

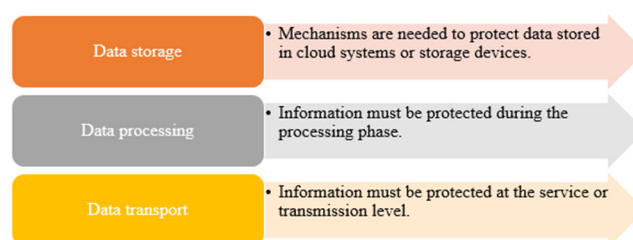


Figure 1. Information processes

Many organizations today depend on complex and interconnected communication systems. These systems are closely related to physical and human factors, which makes them difficult to manage. No complex system can rely solely on physical or technical aspects. Human factors (social engineering) play a crucial role in the continuous operation and maintenance of any complex system. This article presents an analysis of potential threats to critical information infrastructure through ICT services. In addition, a theoretical model of security on demand is developed and threats to business-oriented infrastructures are identified. The proposed method is based on a mathematical model integrated with security policies.

FUNDAMENTALS OF CRITICAL INFRASTRUCTURE PROTECTION

Critical infrastructure protection

Almost all technical systems that are essential for the normal functioning of our daily lives are included in the critical government infrastructure. In particular, these include finance, energy, food supply, healthcare, water resources, transport, telecommunications, education and other sectors[1].

These infrastructures are dependent to a greater or lesser extent on critical information infrastructures. Information systems and communication tools play a very important role in the uninterrupted operation of these infrastructures. Connecting critical infrastructures to the Internet provides the following advantages:

- Reducing costs: allows remote management of large systems.
- Increasing system capabilities: provides sufficient computing resources for low-power hardware.
- Increasing efficiency: increases transaction speed.

However, cyberattacks are increasingly being carried out on infrastructures based on such technological capabilities. Cyberattacks pose a great threat to national information systems and critical infrastructures. In recent years, the number of such attacks has increased, and their complexity has increased. These attacks are widespread due to the interdependence of infrastructures, leading to the failure of important services. The interconnectedness of critical infrastructures makes them vulnerable to cyberattacks. The goal of many cyberattacks is to manipulate IS systems. Such attacks can be carried out in various ways, and distributed denial of service (DDoS) attacks and zero-day attacks have become a common method today.

For example, a failure in communication technologies can affect the entire national economy, starting from the level of an individual business. The failure of infrastructures in the oil and gas, energy or healthcare sectors has a direct impact on other sectors.

Attacks on critical infrastructure

There have been several attacks in history that have threatened critical infrastructures. Attacks targeting SCADA (Supervisory Control and Data Acquisition) systems have directly threatened many companies and government organizations.

DDoS attack on US banks: Several banks in the US were attacked with DDoS attacks, which allowed hackers to steal millions of dollars. Modern approaches to assessment take into account innovations in the field of cyberattacks and apply advanced technologies to improve the level of security[2]. According to ENISA's 2023 Cyber Attack Data, healthcare data and service availability have been the target of numerous attacks over the years[3]. In 2022, a US-based professional financial services company suffered a data breach involving 650 healthcare organization patients. In 2020, SolarWinds' Orion platform was targeted, specifically its software update versions 2019.4 Patch 5, 2022.2 Unpatched, and 2022.2 Patch. Other attacks against power grids have targeted components in both the cyber and physical domains, as shown. The platform is a tool used by IT professionals and government organizations[4]. In 2019, various attacks were carried out targeting oil and gas facilities in the Middle East[5]. Additionally, in 2021, Norway's water

treatment infrastructure fell victim to ransomware known as Ryuk, where attackers encrypted company files and demanded a substantial ransom [6]. Furthermore, Advanced Persistent Threats continue to pose serious risks identified by FireEye researchers in 2017. This group specifically targeted government institutions and financial, energy, chemical, and telecommunications sectors across the Middle East [7]. Attacks on such critical infrastructures have become increasingly frequent. NASDAQ stock market crash: A computer glitch in the Dow Jones industrial average caused a drop in prices on stock exchanges around the world.

Such attacks also pose a threat to government information infrastructure. Failure to ensure the security of government data can lead to the weakening of entire government systems.

A CYBERSECURITY MODEL

Cybersecurity model

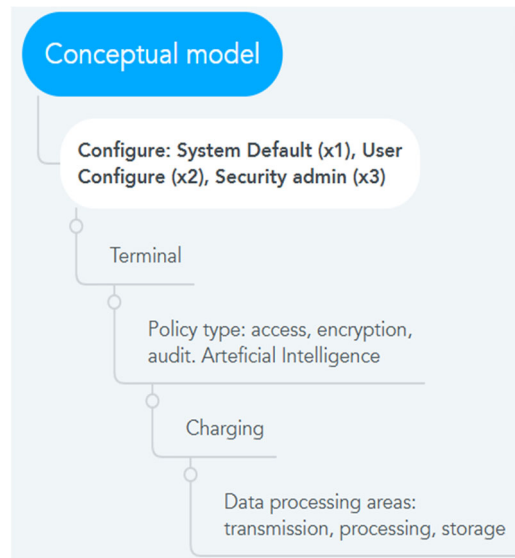


Figure 2. A cybersecurity model

Figure 2 shows how a conceptual security model can be implemented in a telecommunications environment using an ICT-based on-demand security model.

Let the vectors be a set of security units:

D_1 is the set of security units for the data transmission domain, D_2 is the set of security units for the data processing domain, D_3 is the set of security units for the data storage domain.

These sets are subsets of the set D : $D_1 \subset D$, $D_2 \subset D$, where D_1 , D_2 , D_3 are the vectors of security parameters for the three domains mentioned above. The vector of security parameters is expressed as: $D_1(x_1, x_2, x_3)$, where: x_1 is the service type, x_2 is the data location, x_3 is the security level. The on-demand security for ICT-based telecommunications services is calculated using the following formula:

$$D_1 \times D_2 \times D_3 \quad (1)$$

where \times is the operator for unifying security solutions for the three domains. The security units in S_i include security functions such as encryption, authentication, and integration. These functions are implemented in the ICT platform during the research and development (R&D) phase. M_i are security assessment models that should be used in the Security Management Center. In the proposed model, two parameters need to be configured: Security location (x_2) and service type (x_1) are set by the security administrator. Security requirement (x_3) is determined based on the user's needs. After the ICT platform and service are selected, the parameters x_1 and x_2 remain static, while the parameter x_3 is changed based on the user's requirements.

Advantages of the security domain model: Easy configuration – only three parameters (x_1 , x_2 , x_3) need to be configured, which simplifies the management of the entire system.

Domain independence – each domain develops its own security policy, so if one domain is changed, it does not affect the others. Easy implementation of security technologies – since it is based on a security policy model, it allows you to easily develop security modules. At the same time, existing networks, services and data storage devices are used, and only an interface for configuring policies is added. Feedback with the cost accounting center – the results of security policy execution can be provided to the cost accounting center, which allows you to provide security services on demand.

Example of using the model

Alice is working in an Internet cafe. Bob and George are working in an office. Alice makes a video call with Bob and starts a text chat with George to discuss a secret strategy. The video conferencing server selects a security mechanism for each participant based on the following data:

Location (determined by IP address), Type of service,

The security level selected by the user. Since Alice is in an Internet cafe, her authentication is more stringent (password and USB key), while for Bob and George only a password is sufficient. Due to the high level of confidentiality, at least 256-bit AES encryption algorithm is used for all participants. To ensure fast operation, data integrity protection between Alice and Bob is disabled, but remains enabled to prevent text messages between Alice and George from being modified.

The proposed on-demand security model can be expanded and adapted for use in various ICT environments. In particular, the following areas of improvement can be considered: automatic selection of security parameters.

In the current model, some parameters (x_1 and x_2) are set manually by the security administrator, while parameter x_3 is defined by the user. However, it is possible to introduce a mechanism for automatically selecting the security configuration: Machine learning that analyzes the type of traffic, user actions and the context of use, Real-time contextual analysis of threats, Dynamic updating of security policies based on current data, Integration with cloud services and artificial intelligence can also be used. Cloud solutions, which are widely used in modern ICT systems, require flexible and adaptive protection. The expanded version of the model includes: support for multi-cloud environments, automatic adaptation of policies depending on the infrastructure and services, advanced access control and encryption mechanisms for distributed data.

Now let's prototype the theoretical example described above in a practical way (Listing 1). This code fragment is designed to train a model that predicts the security level based on features such as the user's location, device, service, communication type, and time of day. The variables are first converted to numerical values (Label Encoding). Then, the model is trained using the RandomForestClassifier algorithm.

```
# Преобразуем
df = pd.DataFrame(data)
df["Location"] = df["Location"].map(location_map)
df["Device"] = df["Device"].map(device_map)
df["ServiceType"] = df["ServiceType"].map(service_map)
df["CommunicationType"] = df["CommunicationType"].map(communication_map)
df["TimeOfDay"] = df["TimeOfDay"].map(time_map)
df["SecurityLevel"] = df["SecurityLevel"].map(level_map)

X = df[["Location", "Device", "ServiceType", "CommunicationType", "TimeOfDay"]]
y = df["SecurityLevel"]

# Обучаем
model = RandomForestClassifier(n_estimators=100)
model.fit(X, y)
```

Listing 1. Train model

This code fragment shows the main route of the Flask server (listing 2). The user selects an HTML form to receive information about the service, communication type, and location. In addition, the server automatically calculates the device type (User-Agent) and the current time.

Based on these parameters, the system creates a numerical vector and feeds it into the trained model. As a result, the security level is predicted and displayed on the HTML page.

```
# Определяем тип устройства
ua = request.headers.get('User-Agent') or ""
device = "Mobile" if any(x in ua for x in ["Mobile", "Android", "iPhone"]) else "Desktop"

# Время суток
hour = datetime.now().hour
if 6 <= hour < 12:
    time_of_day = "Morning"
elif 12 <= hour < 18:
    time_of_day = "Afternoon"
else:
    time_of_day = "Night"
```

Listing 2. The main logic of a Flask

Listing 3 visually displays the security level result received from the Flask server. The result is presented to the user as "Low", "Medium", or "High". This component simply illustrates the system's reasoning.

```
<body>
  <div class="result-box">
    <h2>Рекомендованный уровень безопасности</h2>
    <p>Для выбранных параметров уровень защиты:</p>
    <p><strong>{{ level }}</strong></p>
    <br>
    <a href="/">← Вернуться к форме</a>
  </div>
</body>
```

Listing 4. Output the prediction result (result.html)

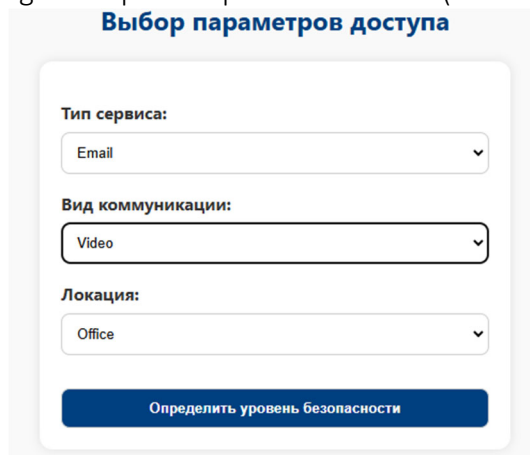


Figure 3. The interface of model

This is just an example implementation. In fact, there is a lot of work ahead. By adding generative artificial intelligence, we can automatically determine the geolocation of the user by their IP address. Using artificial intelligence, we will perform cryptographic operations and determine in real time whether an attack has been committed.

This model can be adapted to protect the following critical infrastructure facilities: energy networks, transport systems, government information systems. In this case, the following factors should be taken into account:

- Compliance with strict regulatory standards,
- Low decision-making latency in the event of cyberattacks,
- High reliability of security solutions.
- Development of security effectiveness assessment metrics

To objectively assess the effectiveness of the model, the following metrics can be developed: threat response time, system performance at different security levels, number of attacks prevented, level of compliance with user requirements. Digital twins can be used as a tool for testing and optimizing the model. This provides the following capabilities: Simulation of

potential attacks and testing response scenarios, Determination of optimal security parameters, Increase in system stability without testing in a real environment.

Offered information about the safety of data processing and transmission

SHA (Safe Hashing Algorithms) is a family of cryptographic hash functions capable of accepting messages of any length and calculating a unique hash code of a fixed length. Hash code SHA can be used to check the integrity of the message, as well as to generate a digital signature of the message.

Two common examples of hash functions are Secure Hash Algorithm (SHA), most commonly SHA-1, and Message-Digest Algorithm 5. SHA-1 is used in many common security systems, including SSL, TLS, S/MIME, and IPSec. MD5 is used to create a digital fingerprint, which is used to verify the integrity of files.

Symmetric encryption works quickly, but key exchange is a problem. Asymmetric encryption provides more opportunities from the point of view of security, but it works slowly. Solution: combine them into a hybrid system. This is how cryptosystems based on digital certificates work, which are widely used for e-mail, instant messaging and SSL/TLS web traffic.

To process and transfer information between three parties (Alice in the cafe, Bob in the office and George in the office), where the cryptographic system uses a hash function.

The hash function H converts a long text P into a shorter value $H(P)$. For example, if P has a length of 1245 bits, then $H(P)$ can be only 124 bits. Thus, $H(.)$ is a multivalued function, that is, different texts P can give the same value $H(P)$.

The hash function must be difficult to calculate for the pseudo-inverse transformation. That is, having the value M , it is extremely difficult to select the text P' , such that $H(P') = M$. Depending on the field of application, additional properties may be required:

Property 1: Having both P and $H(P)$, it should be difficult to find $P' \neq P$ such that $H(P') = H(P)$. This condition is more strict than the previous one, since the knowledge of P can facilitate the search for P' .

Property 2: It should be difficult to find two different strings P and P' such that $H(P) = H(P')$.

Property 3: If P is known, but string K is unknown, it should be difficult to find $P' \neq P$, such that $H(KP') = H(KP)$, where KP denotes the concatenation of strings K and P (for example, $10011011101 = 10011011101$).

Hash functions are primarily used to generate fixed-length data that serves as a shortened reference to the original data. This is useful when the source data is too large for immediate use.

One of the practical examples is a hash table in which data is stored in an associative structure. For example, the search for a name in the list can be slow, but the hash value allows you to quickly find a link to the original data and extract it in a constant time (in the absence of collisions).

Using AI in the model

Generative artificial intelligence can also contribute to improving cybersecurity. The authentication and security policies mentioned in the conceptual model can be created using AI & machine learning. Figure 3 shows a diagram of the use of AI. The AI can select the authentication and encryption system according to the location of each user.

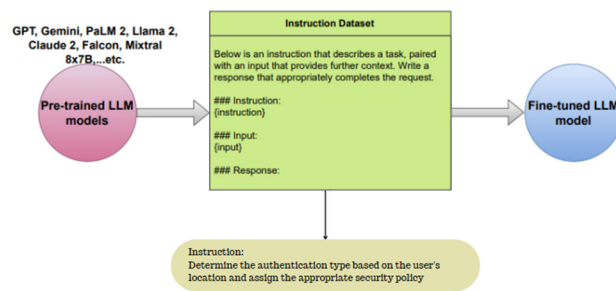


Figure 3. Conceptual model with AI

The introduction of artificial intelligence and machine learning (ML) into cybersecurity is a significant step in combating sophisticated cyberattacks. As these technologies become an important part of security systems, there is a need for strategic oversight of their operation. Such oversight should be aimed at maintaining a balance between maximizing the potential of AI capabilities and ensuring compliance with ethical standards.

Effective oversight mechanisms may include: rigorous testing periods, continuous monitoring of AI behavior, development of structures that ensure accountability for AI decisions.

The future of AI in cybersecurity depends on research aimed at expanding the capabilities of current technologies, as well as overcoming their limitations. Promising research areas include: Autonomous response systems - the development of AI systems that can not only detect threats, but also respond automatically in real time, which minimizes the need for human intervention.

Defense against AI - the study of methods for combating situations in which cybercriminals use AI technologies to bypass security systems.

Privacy-preserving technologies – ensuring the confidentiality of user data in AI systems using techniques such as collaborative learning and differential privacy.

Despite the advantages of introducing AI into cybersecurity, several important issues remain:

Data confidentiality – AI systems require large amounts of data to function effectively, so ensuring their security is one of the main tasks.

Continuous learning and adaptation – AI models must be constantly updated and adapted to new threats. This is necessary to maintain the fairness of the learning process and prevent systems from becoming obsolete.

Threat of manipulation – there is a risk that experienced cyber attackers will bypass or distort AI-based security systems. Therefore, it is necessary to develop reliable systems that can detect and prevent such actions.

Addressing these issues requires a balanced approach between promoting technological innovation and strict adherence to ethical standards and security practices. Collaboration between academia, industry, and government organizations can contribute to the development of standards and best practices that govern the ethical use of AI in cybersecurity.

By focusing on these strategic directions, the cybersecurity community can responsibly and effectively leverage the capabilities of AI, enabling a secure digital future.

CONCLUSION

As the world becomes more and more encrypted, countries are actively developing cyber defense measures and policies. Although the importance of critical information infrastructure (CII) is currently very high, there are no reliable tools to fully protect it.

The solution proposed in this paper focuses on the use of hashing techniques. It is not limited to the threat prevention stage (for example, data storage and authentication), but also applies to the data processing and transmission stages. Future research will be focused on improving hash functions to avoid collisions, using reliable hash keys based on additional

parameters (biometric data, passwords, IP addresses, etc.), and using elements of artificial intelligence and machine learning.

In addition, the article presents a conceptual model of security divided into domains, which has four main advantages:

Ease of implementation: Only three parameters (service type, data location, and security level) need to be configured, which simplifies management.

Domain Independence: The policies of each security domain are developed separately, which allows changes to be made without affecting each other.

Scalability and Flexibility: The implementation of security technologies is carried out through policy models, which allows for easy integration of new security modules into existing networks, services, and storage systems.

Feedback and Cost Accounting: The results of policy execution can be provided to a cost accounting center, which allows for the provision of security services on-demand.

Thus, this work contributes to improving the protection of critical infrastructure in the face of ever-increasing cyber threats.

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Darkness That Teaches: A Conceptual Framework for Fear-Based Learning in AR/VR Through Folk-Legend Horror Games

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Abstract. Conventional education treats fear as an obstacle to learning and works to remove it. Yet research on emotional memory and recreational horror suggests the opposite may hold under controlled conditions: moderate, narratively framed fear can sharpen attention, strengthen memory consolidation, and serve as low-stakes practice for emotional regulation. This paper asks how augmented and virtual reality (AR/VR) can be designed to harness controlled fear for educational ends, with cultural heritage delivered through folk-legend narrative as the content. Using a structured synthesis of peer-reviewed work across four domains—the psychology of fear and memory, recreational horror as threat simulation, immersive learning theory, and serious games for heritage—the paper derives a conceptual framework, *Darkness That Teaches*, that links folk-legend narrative, immersive presence and agency, a calibrated fear-arousal window, and affective–cognitive learning processes to three target outcomes: cultural-heritage knowledge, emotional-regulation skill, and durable retention. The framework is operationalised as a design model with an AI-driven arousal-calibration loop that keeps each learner inside an optimal-fear window. The contribution is conceptual: it addresses the standard objection that fear impairs cognition, formulates testable design principles and hypotheses, and sets out an empirical agenda rather than reporting a trial. The intersection of folk-legend horror, AR/VR immersion, and formal learning outcomes is, to the authors' knowledge, not yet addressed in the literature.

Keywords: augmented reality; virtual reality; fear-based learning; recreational horror; emotional regulation; immersive learning; folk legend; serious games; cultural heritage.

1. Introduction

Fear is one of the oldest and most consequential human emotions. At the level of mechanism it recruits the amygdala, narrows and intensifies attention, and modulates the consolidation of memory, so that emotionally arousing events are typically remembered better and longer than neutral ones [2]. Education has tended to read this relationship in only one direction: fear is anxiety, anxiety impairs performance, and the classroom should therefore be made as unthreatening as possible. The premise of this paper is that the relationship is not monotonic. The classical arousal–performance account [1] describes an inverted-U: performance rises with arousal up to an optimum and falls beyond it. Read through that account, the design question is not whether to exclude fear but how to hold it inside a productive band (Figure 1).

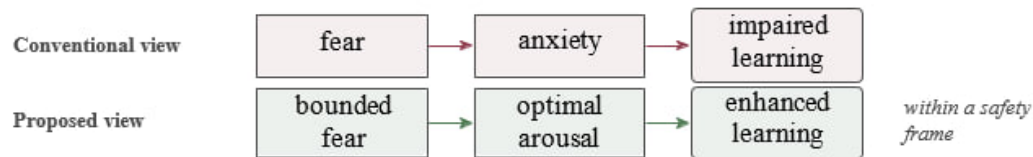


Figure 1. The reframe at the heart of this paper. Education usually assumes fear is monotonically harmful (top); the inverted-U and recreational-horror evidence imply that bounded, safely framed fear can instead enhance learning (bottom).

Two lines of evidence make that question more than rhetorical. First, work on recreational horror

shows that people deliberately seek frightening experiences and derive the most enjoyment when fear is intense enough to register physiologically but not so intense as to overwhelm—an empirically located “sweet spot” of fear [3]. Second, engagement with frightening fiction appears to function as rehearsal: horror fans and morbidly curious individuals reported greater psychological resilience during the COVID-19 pandemic, consistent with the view that frightening fictions let audiences practise coping strategies in safety [4, 5]. If fear can be both bounded and generative, then a medium that can stage it precisely becomes educationally interesting.

AR and VR are such a medium. Immersive learning theory holds that the two affordances unique to immersive technology—presence and agency—drive a set of affective and cognitive factors (interest, motivation, self-efficacy, embodiment, cognitive load, self-regulation) that in turn shape learning outcomes [6]. Because immersive presence produces autonomic responses comparable to real situations while the learner retains awareness of the fictional frame, AR/VR is unusually well suited to delivering controlled fear. A recent pedagogical experiment found that VR horror evoked significantly stronger fear and related emotions than equivalent screen-based horror, and that participants reported it helped them learn to manage stress and negative emotion [8].

The content vehicle proposed here is folk legend. Serious games are an established route to cultural-heritage learning, turning historical and sociological content into engaging interaction [9]. Folk legend is a natural fit for horror: it already encodes a culture’s fears, taboos, and moral lessons in narrative form. What is missing is the synthesis. No prior work, to the authors’ knowledge, examines AR/VR horror grounded in folk-legend narrative as a deliberate medium for formal learning outcomes. This paper sets out to close that gap conceptually.

Aim. To formulate and justify a conceptual framework for fear-based learning in AR/VR that uses folk-legend horror as its content vehicle, and to translate it into actionable design principles.

Objectives.

1. synthesise evidence across the psychology of fear, recreational horror, immersive learning, and serious games for heritage;
2. identify the mechanism by which bounded fear can support rather than impair learning;
3. derive a framework linking narrative, immersion, fear arousal, and learning outcomes;
4. specify a design model, including arousal calibration, and a set of design principles;
5. state the ethical constraints and the empirical agenda needed to test the framework.

This work is situated within a dissertation project developing a horror-genre educational game in Unity 3D based on a folk legend of an abandoned house in the Medeu gorge near Almaty, Kazakhstan—a mountain site of considerable local significance. The present paper is its theoretical foundation; the game itself serves throughout as the running illustrative case.

2. Literature review

This section synthesises the evidence the framework rests on, organised by the four domains introduced above. The criteria by which these sources were selected, and the design-science procedure used to build on them, are set out in Section 3.

2.1 Fear, arousal, and memory

Emotional arousal modulates memory at encoding and consolidation: events that engage the amygdala are preferentially retained, which is why emotionally charged material is remembered more vividly and durably than neutral material [2]. Arousal is not, however, simply “more is better.” The arousal–performance relationship is an inverted-U [1]: there is an optimum beyond which

additional arousal degrades performance, and the location of that optimum depends on task and individual. For design, the implication is precise—the goal is to place each learner near the top of the curve, not to maximise fear.

2.2 Recreational horror as threat simulation

People voluntarily pay to be frightened, which is paradoxical unless fear under safe conditions carries a benefit. Field research in a haunted attraction located a sweet spot at which a clear physiological fear response coincides with maximal enjoyment, with the boundary between fun and distress varying between individuals [3]. Complementary survey work links horror fandom and trait morbid curiosity to psychological resilience, supporting a threat-simulation account in which frightening fiction is rehearsal for real adversity [4, 5]. Together these results convert “fear” from a hazard into a designable, individually calibrated resource.

2.3 Immersive learning: presence, agency, and affect

The Cognitive Affective Model of Immersive Learning (CAMIL) holds that immersive technology’s two distinctive affordances—presence and agency—activate affective and cognitive factors (interest, intrinsic motivation, self-efficacy, embodiment, cognitive load, and self-regulation) that mediate learning in immersive VR [6]. This matters here for two reasons. First, it gives a principled account of *why* immersion changes learning rather than merely asserting that it does. Second, the same presence that produces learning also produces genuine autonomic fear while the fictional frame is preserved—exactly the combination needed for safe, generative fear. Empirically, VR horror has been shown to elicit stronger fear than screen-based horror and to be perceived as supporting emotional-regulation skill [8]. Crucially, CAMIL treats immersion as a *continuum* rather than a binary: findings from less immersive media are expected to generalise along it, with presence rising as the medium becomes more immersive [6] (Figure 2). A screen-based 3D game therefore already sits on the immersive spectrum; head-mounted VR is its higher-presence extreme.

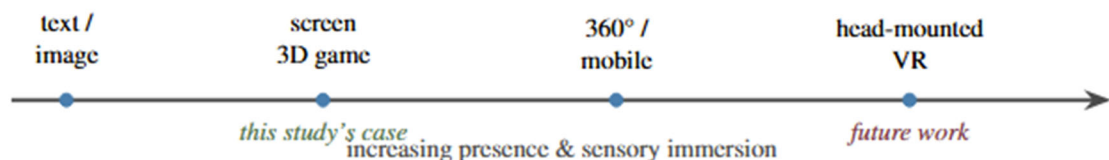


Figure 2. Immersion as a continuum (after CAMIL [6]). Presence rises from left to right; a screen-based 3D horror game and full VR are points on the same spectrum.

2.4 Serious games, heritage, and folk legend

Serious games are a validated medium for cultural-heritage education, embedding historical and sociological content in interactive experience [9]. Folk legend is a particularly apt payload: it is

narrative by construction, it carries a community's history and values, and its recurring motifs are frequently fearful. Pairing heritage content with horror is therefore not a gimmick but an alignment between the affective grammar of the genre and the affective content of the source material.

2.5 Synthesis

Table 1 consolidates the reviewed evidence and states, for each source, the specific claim the framework relies on. Read together, the rows form a chain: arousal aids memory within an optimum; fear can be held at that optimum and is enjoyable and rehearsal-like there; immersion amplifies the affective route to learning; and serious games can carry heritage content.

3. Methodology

This is a conceptual, design-oriented study; it does not report an empirical trial. It combines the structured literature synthesis presented in Section 2 with a design-science derivation of a framework

Table 1. Evidence synthesis: the claim each source contributes to the framework.

Source	Domain	Claim used in the framework
Yerkes & Dodson [1]	Arousal & performance	An arousal optimum exists; performance follows an inverted-U and falls under over-arousal.
LaBar & Cabeza [2]	Emotion & memory	Emotional arousal strengthens memory encoding and consolidation.
Andersen et al. [3]	Recreational horror	An empirical “sweet spot” of enjoyable fear exists and varies between individuals.
Scrivner et al. [4, 5]	Horror & resilience	Engagement with frightening fiction is linked to resilience (threat simulation).
Makransky & Petersen [6]	Immersive learning	Presence and agency drive the affective–cognitive factors behind learning.
Wojciechowski [8]	VR horror	VR horror raises fear vs. screen-based horror and is perceived to support regulation.
Mortara et al. [9]	Serious games & heritage	Serious games are an effective vehicle for cultural-heritage content.

(Section 4)—moving from established findings to design principles to a proposed artefact. This section sets out how the reviewed sources were selected and how the framework was derived from them. Design-science reasoning is appropriate because the intended contribution is an artefact—a framework and an associated design—rather than an empirical estimate; its validity therefore rests on the soundness of the mechanisms it chains together and on whether it yields falsifiable predictions, both of which are examined in the Discussion.

Peer-reviewed sources were sought in Scopus, Web of Science, and Google Scholar using combinations of the terms *immersive learning*, *VR/AR education*, *psychology of fear*, *recreational horror*, *emotion regulation*, and *serious games heritage*. Sources were retained when they (a) were peer-reviewed; (b) bore directly on one of the four domains reviewed in Section 2; and (c) were either foundational (for theory) or recent (for the state of the art). The review is narrative and

thematic rather than an exhaustive systematic review in the PRISMA sense; its purpose is to assemble the mechanisms needed to build a framework, not to estimate a pooled effect size. Figure 3 summarises the selection process and the four analytical domains feeding framework derivation.

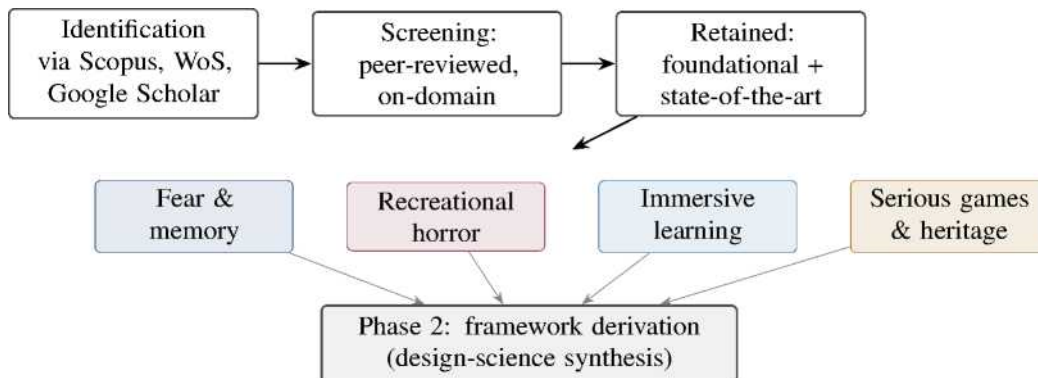


Figure 3. Source-selection process and the four analytical domains feeding framework derivation.

4. Results: the *Darkness That Teaches* framework

4.1 Structure

Synthesising the four domains yields a five-layer framework (Figure 4). A folk-legend *narrative* supplies meaning, safety framing, and cultural content. AR/VR *immersion* converts that narrative into presence and agency. Presence drives a controlled *fear arousal* held within an optimal window. That arousal feeds the CAMIL *affective–cognitive* factors, which produce three *outcomes*: cultural- heritage knowledge, emotional-regulation skill, and durable retention. Read left to right, each layer is the documented cause of the next; the framework is thus a chain of established mechanisms rather than a single untested claim.

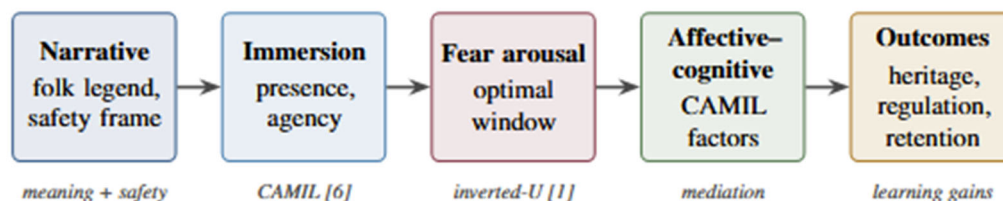


Figure 4. The five-layer *Darkness That Teaches* framework. Each layer is the documented antecedent of the next; bracketed numbers indicate the supporting source.

4.2 The optimal-fear window

The framework’s pivot is the third layer. The inverted-U [1] and the recreational “sweet spot” [3] jointly imply a band of fear arousal within which engagement, attention, and encoding are enhanced, flanked by an under-aroused region (boredom, low encoding) and an over-aroused region (distress, avoidance, impaired performance). Figure 5 makes the design target explicit: the system should drive each learner toward the shaded band and keep them there.

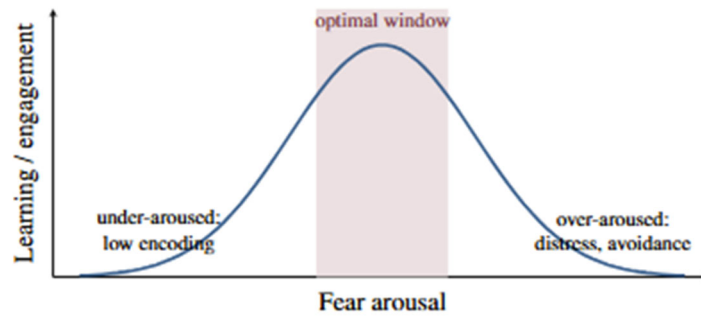


Figure 5. The optimal-fear window: an inverted-U relationship between fear arousal and learning, with the design-target band shaded. After [1] and [3].

4.3 Design model: AI-driven arousal calibration

Because the window's location varies by learner [3], a single fixed intensity will over-frighten some and bore others. The framework therefore includes a closed-loop calibration mechanism (Figure 6). The player's affective state is estimated—from self-report and, where available, physiological signals such as heart-rate variability—and classified relative to the optimal window. A controller then adjusts scene intensity (pacing, proximity of threat, audio, lighting) to nudge arousal back toward the band. The loop instantiates the safety frame in software: it is the mechanism that keepfear generative rather than harmful.

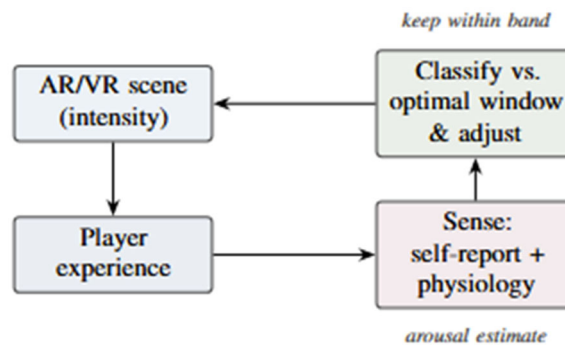


Figure 6. Closed-loop fear calibration: the system continuously steers each learner toward the optimal-fear window.

4.4 Mapping legend to learning objectives

Heritage learning requires that narrative elements carry explicit objectives. Table 2 applies this rule to the running case—the legend of an abandoned house in the Medeu gorge—so that every frightening beat also teaches something. The entries describe the design and the general didactic function of cautionary folk legend; the specific narrative content is supplied by the game. Designers working from a different legend adapt the same four-way mapping.

Table 2. Worked example: mapping elements of the Medeu abandoned-house legend to learning objectives. Specific narrative content is supplied by the game.

Legend element	Fear / horror function	Learning objective
Abandoned house in the Medeu gorge	Primary locus of dread; isolation and decay	Geography and recent history of the Medeu mountain area near Almaty
The legend's haunting presence	Unpredictable threat and pursuit (AI-driven)	The cautionary, moral function of oral folk legend
Transgression (disturbing the house)	The consequence the player comes to fear	Social norms and warnings such legends transmit
Period artefacts in the house	Investigative interaction under tension	Material culture and everyday life of the period

4.5 Design principles

The framework yields six principles:

1. **Frame for safety.** Make fictionality and survivability salient so arousal stays generative [3].
2. **Calibrate, don't maximise.** Target the optimal window per learner, not peak fear [1].
3. **Bind fear to content.** Every scare should deliver a heritage objective (Table 2) [9].
4. **Exploit presence and agency.** Use the affordances that actually drive immersive learning [6].
5. **Build in regulation practice.** Provide moments to appraise and down-regulate fear, making coping an explicit skill [4].
6. **Make exit costless.** A always-available, non-penalising way out is both an ethical and a calibration requirement.

5. Discussion

5.1 Implications

The framework reframes a long-standing assumption. Rather than asking how to remove fear from learning, it asks how to place fear precisely, and it grounds that placement in independently established mechanisms: emotional modulation of memory [2], the arousal optimum [1], the recreational sweet spot [3], threat-simulation resilience [4], and the presence/agency pathway of immersive learning [6]. Its novelty is the integration plus the heritage payload: folk legend as a horror medium for formal learning.

5.2 When fear impairs: boundary conditions

The framework must answer the obvious objection that fear and anxiety routinely *impair* cognition. The objection is correct—but only about the wrong side of the curve. The inverted-U [1] predicts impairment precisely when arousal exceeds the optimum, and the recreational evidence shows the same: beyond the sweet spot, fear stops being enjoyable and becomes distress [3]. The framework does not deny this; it is built around it. Three boundary conditions follow. (i) *Intensity*: benefits hold only inside the optimal window, which is exactly why calibration (Figure 6) is central rather than optional. (ii) *Framing*: the same arousal is generative under a salient safety frame and harmful without one—fear must be recognisably fictional and survivable [3]. (iii) *Individual differences*: the window's location varies, so a fixed intensity will over-arouse some learners; for individuals with anxiety or trauma histories the productive window may be narrow or absent, and for them the design should not be used. Stated this way, the apparent contradiction dissolves: the framework claims a benefit for *bounded, framed, calibrated* fear, not

for fear in general.

5.3 Ethical considerations

Deliberately inducing fear in learners carries obligations that a design must meet before it is deployed. (i) *Informed consent*: participants must understand they will be frightened and agree in advance. (ii) *Costless exit*: the always-available exit (Principle 6) is a safety requirement, not only a feature. (iii) *Individual differences*: because the window varies, and because some learners have trauma or anxiety histories, screening and per-learner calibration are mandatory; the same scene that is optimal for one learner may be harmful for another. (iv) *Minors*: where learners are under 18, age-appropriate intensity ceilings, guardian consent, and supervision are required, and the most intense configurations should be disabled. (v) *Data*: physiological sensing implies sensitive-data handling and must follow applicable privacy rules. These constraints are part of the framework, not caveats to it.

5.4 Limitations

The study is conceptual and reports no trial; the framework is a hypothesis to be tested, not a validated result. Direct empirical evidence for VR *horror* as a learning tool is still thin, resting substantially on a single recent experiment with a specific population [8]; much of the supporting literature concerns immersive learning or recreational horror in general rather than their intersection. The AI calibration loop assumes affect estimation that is reliable enough to steer intensity safely, which current sensing does not guarantee. Finally, the folk-legend payload has not been instantiated or evaluated.

5.5 Proposed empirical evaluation

The framework is valuable only if it is falsifiable. The natural test is a between-subjects experiment delivering *identical* heritage content under three conditions: an immersive bounded-fear version (the folk-legend horror game), an immersive neutral version (the same environment and content without the horror framing), and a non-immersive version (the same material as text or slides). This 2-by-2-style contrast lets the design separate the contribution of immersion (immersive vs. non-immersive) from that of fear (fear vs. neutral), rather than confounding the two. Learners would be screened for anxiety and trauma history, randomly assigned, and run under the informed-consent, costless-exit, and supervision safeguards described above. Heritage-knowledge acquisition would be measured immediately and after a delay (for example two weeks) so that the design captures durable retention rather than short-term recall; emotional-regulation skill would be assessed before and after with an established reappraisal measure; and presence together with experienced arousal would be logged to confirm both that the conditions differed as intended and that fear remained within the optimal window. Table 3 states the hypotheses that follow and the measure attached to each. A first study should be modest and exploratory: its purpose is to establish feasibility, safety, and the direction of any effect, not to deliver definitive effect sizes.

Table 3. Testable hypotheses derived from the framework, with the link tested and a candidate measure.

	Hypothesis	Link tested	Candidate measure
H1	Bounded-fear delivery yields better heritage-knowledge retention than a neutral version of the same content.	fear → outcomes	delayed knowledge test
H2	Higher immersion amplifies the fear-to-retention effect relative to lower immersion.	immersion → affect	presence scale + retention
H3	Repeated calibrated exposure improves emotional-regulation skill.	fear → regulation	pre/post reappraisal measure
H4	Per-learner calibration keeps more learners in the optimal window than fixed intensity, lowering distress and dropout.	calibration loop	arousal/distress + completion

6. Conclusion

This paper set out to reframe a long-standing assumption in education—that fear is an obstacle to be removed—and to show that, bounded and narratively framed, fear can instead be a resource for learning. It did so in five steps. It synthesised four bodies of evidence (the psychology of fear and memory, recreational horror as threat simulation, immersive-learning theory, and serious games for heritage) into the *Darkness That Teaches* framework, a chain of established mechanisms linking folk-legend narrative, immersive presence and agency, a calibrated fear-arousal window, and affective–cognitive processing to three learning outcomes. It translated that framework into a design model with per-learner arousal calibration and six concrete design principles. It confronted the central objection—that fear impairs cognition—and resolved it through explicit boundary conditions. And it set out the ethical constraints under which such a system may be used, treating them as part of the framework rather than as afterthoughts.

The significance is twofold. For the learning sciences, the framework offers a precise, mechanismbased account of *when* and *why* fear can aid rather than hinder learning, turning a vague intuition into a set of testable claims. For cultural heritage, it proposes a route by which a local folk tradition— here, the legend of the abandoned house in the Medeu gorge—can be preserved and transmitted through a medium that young learners actively seek out rather than endure. This matters particularly for contexts such as Kazakhstan, where a rich body of oral legend risks fading from the attention of a screen-native generation; framing that heritage as horror meets those learners on ground they already choose to occupy.

Even ahead of the empirical test, the framework is usable. Its six design principles give developers of educational horror games a principled checklist—frame for safety, calibrate rather than maximise, bind every scare to a learning objective, exploit presence and agency, build in regulation practice, and keep exit costless—in place of intuition, and its ethical constraints make explicit what such a design owes its players before it is deployed. The immediate next step is the controlled study outlined above and in Table 3, measuring heritage-knowledge acquisition, emotional-regulation development, and retention against immersive-neutral and non-immersive controls, with the safety and consent procedures described. The wider claim—that “darkness” can teach—remains a hypothesis; the contribution of this paper is to have made it a precise and

falsifiable one.

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Paylanmış hesablama mühitində Apache Spark platformasının tətbiq imkanları

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Xülasə

Müasir dövrdə rəqəmsal texnologiyaların inkişafı, internet xidmətlərinin genişlənməsi və müxtəlif informasiya sistemlərinin fəaliyyətinin artması nəticəsində yaradılan məlumatların həcmi sürətlə çoxalmaqdadır. Böyük verilənlər (Big Data) adlandırılan bu məlumatların emalı ənənəvi hesablama sistemləri üçün ciddi çətinliklər yaradır və daha məhsuldar texnologiyaların tətbiqini zəruri edir. Bu məqsədlə paylanmış hesablama mühitləri və böyük verilənlərin paralel emalını təmin edən platformalar geniş istifadə olunmağa başlanmışdır. Belə platformalar arasında Apache Spark yüksək məhsuldarlığı, operativ yaddaş əsaslı işləmə mexanizmi və geniş funksional imkanları ilə xüsusi yer tutur. Apache Spark böyük həcmli verilənlərin sürətli emalına imkan verməklə yanaşı, real vaxt məlumat axınlarının təhlili, maşın öyrənməsi və verilənlər analitikası kimi sahələrdə də geniş tətbiq olunur.

Məqalədə Apache Spark platformasının nəzəri əsasları, arxitekturası və iş prinsipi araşdırılmışdır. Spark ekosisteminin əsas komponentləri, o cümlədən Spark SQL, Spark Streaming, MLlib və GraphX modullarının funksional imkanları təhlil edilmişdir. Həmçinin platformanın böyük verilənlərin analitikası, kibertəhlükəsizlik, dövlət informasiya sistemləri və maşın öyrənməsi sahələrində tətbiq imkanları qiymətləndirilmişdir.

Müasir müəssisələr və təşkilatlar tərəfindən böyük verilənlərin emalı üçün geniş istifadə olunan Apache Spark platforması müxtəlif mənbələrdən daxil olan məlumatların inteqrasiyasını və operativ təhlilini təmin edir. Platformanın çevik arxitekturası fərqli verilənlər formatları ilə işləməyə imkan verir və mürəkkəb analitik tapşırıqların yerinə yetirilməsini asanlaşdırır. Bu xüsusiyyətlər Spark-in böyük verilənlər ekosistemində mühüm mövqeyə malik olmasına şərait yaradır.

Aparılan təhlillər göstərir ki, Apache Spark yüksək sürət, miqyaslanma qabiliyyəti və çeviklik kimi üstünlüklərə malik olsa da, böyük yaddaş resurslarına olan tələbat və klaster idarəetməsinin mürəkkəbliyi kimi müəyyən məhdudiyyətlər də mövcuddur. Məqalədə bu problemlərin aradan qaldırılması istiqamətində müasir yanaşmalar və platformanın gələcək inkişaf perspektivləri də nəzərdən keçirilmişdir.

Açar sözlər: Apache Spark, böyük verilənlər, paylanmış hesablama, Spark SQL, Spark Streaming, MLlib, verilənlər analitikası.

Giriş

Son illərdə informasiya-kommunikasiya texnologiyalarının sürətli inkişafı nəticəsində yaradılan məlumatların həcmi əhəmiyyətli dərəcədə artmışdır. Sosial şəbəkələr, elektron ticarət sistemləri, mobil tətbiqlər, sensor şəbəkələri və bulud texnologiyaları hər gün böyük həcmdə məlumat formalaşdırır. Bu məlumatların saxlanması, emalı və təhlili ənənəvi hesablama sistemlərinin imkanlarını məhdudlaşdırdığından böyük verilənlərin idarə olunması müasir informasiya texnologiyalarının əsas istiqamətlərindən birinə çevrilmişdir. Böyük verilənlərin effektiv emalı üçün paylanmış hesablama mühitlərinin tətbiqi zəruri hesab olunur. Bu yanaşma

məlumatların bir neçə hesablama qovşağı arasında bölüşdürülərək paralel şəkildə emal edilməsinə və hesablama resurslarından daha səmərəli istifadə olunmasına imkan yaradır [4].

Böyük verilənlərin emalı sahəsində uzun müddət Hadoop və MapReduce texnologiyaları geniş istifadə edilmişdir. Lakin məlumatların disk əsaslı emalı və iterativ hesablama proseslərində yaranan performans məhdudiyyətləri daha sürətli platformalara ehtiyac yaratmışdır. Bu məqsədlə Kaliforniya Universitetinin Berkeley AMPLab tədqiqatçıları tərəfindən Apache Spark platforması hazırlanmışdır. Spark operativ yaddaş əsaslı hesablama yanaşması sayəsində böyük verilənlərin emal sürətini əhəmiyyətli dərəcədə artırır və müxtəlif analitik tapşırıqların daha səmərəli yerinə yetirilməsinə imkan verir [1].

Hazırda Apache Spark böyük verilənlərin analitikası, real vaxt məlumat emalı, maşın öyrənməsi, maliyyə sistemləri, dövlət informasiya sistemləri və kibertəhlükəsizlik kimi sahələrdə geniş tətbiq olunur. Platformanın Spark SQL, Spark Streaming, MLlib və GraphX kimi modulları onun müxtəlif növ verilənlərlə işləməsinə və mürəkkəb analitik məsələlərin həllinə imkan yaradır [3]. Bu xüsusiyyətlər Apache Spark-ı müasir paylanmış hesablama mühitlərinin ən geniş istifadə olunan texnologiyalarından birinə çevirmişdir.

Bu məqalənin məqsədi Apache Spark platformasının nəzəri əsaslarını, arxitekturasını və funksional imkanlarını araşdırmaq, həmçinin onun böyük verilənlərin emalındakı rolunu və tətbiq sahələrini təhlil etməkdir. Bununla yanaşı, platformanın əsas xüsusiyyətləri, mövcud məhdudiyyətləri və gələcək inkişaf perspektivləri də qiymətləndirilmişdir.

Apache Spark platformasının nəzəri əsasları

Apache Spark böyük verilənlərin emalı üçün nəzərdə tutulmuş açıq mənbəli paylanmış hesablama platformasıdır. Platforma ilk dəfə Kaliforniya Universitetinin Berkeley AMPLab tədqiqat qrupu tərəfindən hazırlanmış və sonradan Apache Software Foundation tərəfindən inkişaf etdirilmişdir. Spark-ın yaradılmasında əsas məqsəd mövcud paylanmış hesablama sistemlərində, xüsusilə MapReduce modelində müşahidə olunan performans məhdudiyyətlərini aradan qaldırmaq və böyük həcmli verilənlərin daha sürətli emalını təmin etmək olmuşdur [1].

Apache Spark-ın əsas fərqləndirici xüsusiyyəti operativ yaddaş (in-memory computing) əsaslı hesablama yanaşmasından istifadə etməsidir. Ənənəvi MapReduce modelində aralıq nəticələr diskdə saxlanıldığı halda, Spark həmin nəticələrin böyük hissəsini operativ yaddaşda saxlayaraq giriş-çıxış əməliyyatlarının sayını azaldır. Bu yanaşma xüsusilə iterativ hesablama proseslərində və maşın öyrənməsi tətbiqlərində yüksək məhsuldarlıq əldə etməyə imkan verir [2].

Spark platformasının əsasını Resilient Distributed Dataset (RDD) adlı verilənlər modeli təşkil edir. RDD paylanmış mühitdə saxlanılan və paralel şəkildə emal edilən verilənlər toplusudur. Bu model verilənlərin müxtəlif hesablama qovşaqları arasında bölüşdürülməsinə, paralel emalın həyata keçirilməsinə və sistem nasazlıqları zamanı məlumatların bərpa olunmasına imkan yaradır. RDD mexanizmi Spark-ın həm çevikliyi, həm də etibarlılığını təmin edən əsas texnologiyalardan biri hesab olunur [1].

Apache Spark müxtəlif verilənlər mənbələri ilə işləyə bilən universal platforma kimi layihələndirilmişdir. O, Hadoop Distributed File System (HDFS), Apache Hive, Apache HBase və digər verilənlər saxlama sistemləri ilə inteqrasiya oluna bilər. Bundan əlavə, Spark SQL, Spark Streaming, MLlib və GraphX kimi modullar vasitəsilə strukturlaşdırılmış verilənlərin emalı, real vaxt məlumat axınlarının analizi, maşın öyrənməsi və qraf analitikası kimi müxtəlif funksiyaları dəstəkləyir [3].

Hazırda Apache Spark böyük verilənlərin emalı sahəsində ən geniş istifadə olunan platformalardan biri hesab edilir. Yüksək sürəti, miqyaslı bilmə qabiliyyəti və geniş funksional imkanları sayəsində platforma həm elmi tədqiqatlarda, həm də sənaye tətbiqlərində mühüm rol oynayır [2].

Spark arxitekturası və iş prinsipi

Apache Spark platformasının yüksək məhsuldarlığı onun paylanmış arxitekturası və optimallaşdırılmış hesablama mexanizmləri ilə əlaqədardır. Spark klaster mühitində fəaliyyət göstərir və verilənlərin müxtəlif hesablama qovşaqları arasında bölüşdürülərək paralel şəkildə emal edilməsini təmin edir. Platformanın arxitekturası Driver, Cluster Manager, Worker və Executor komponentlərindən ibarətdir [2].

Spark tətbiqinin idarə olunması Driver proqramı tərəfindən həyata keçirilir. Driver istifadəçi tərəfindən göndərilən tapşırıqları qəbul edir, onların icra planını formalaşdırır və klasterdə yerləşən işçi qovşaqlara paylayır. Resursların idarə olunması isə Cluster Manager tərəfindən yerinə yetirilir. Spark mühitində bu məqsədlə Standalone Manager, Apache Hadoop YARN və ya Apache Mesos kimi resurs idarəetmə sistemlərindən istifadə oluna bilər [3].

Klasterdə yerləşən Worker qovşaqları hesablama resurslarını təmin edir və onların daxilində Executor prosesləri fəaliyyət göstərir. Executor-lar Driver tərəfindən göndərilən tapşırıqları icra edir, aralıq nəticələri yaddaşda saxlayır və yekun nəticələri Driver proqramına qaytarır. Bu yanaşma verilənlərin paralel şəkildə emal edilməsinə və hesablama prosesinin sürətləndirilməsinə imkan yaradır [2].

Spark-ın iş prinsipi əsasən verilənlərin transformasiyası və əməliyyatların icrası mərhələlərinə əsaslanır. İstifadəçi tərəfindən verilən tapşırıq əvvəlcə məntiqi icra planına çevrilir, daha sonra isə optimallaşdırılaraq fiziki icra planı hazırlanır. Spark yalnız nəticənin əldə olunması tələb edildikdə hesablama əməliyyatlarını icra edir. Bu yanaşma "Lazy Evaluation" adlanır və sistem resurslarından daha səmərəli istifadə olunmasına imkan verir [3].

Platformanın əsas xüsusiyyətlərindən biri verilənlərin operativ yaddaşda saxlanmasıdır. Bu yanaşma diskə müraciətlərin sayını azaldığı üçün hesablama sürətini əhəmiyyətli dərəcədə artırır. Xüsusilə iterativ alqoritmlər və maşın öyrənməsi tətbiqlərində Spark ənənəvi MapReduce modelindən daha yüksək performans nümayiş etdirir [1], [7].

Beləliklə, Spark arxitekturası paylanmış hesablama mühitində verilənlərin səmərəli idarə olunmasını, paralel emalını və yüksək məhsuldarlıqla işlənməsini təmin edən əsas texnoloji baza rolunu oynayır.

Spark ekosisteminin əsas komponentləri

Apache Spark yalnız böyük verilənlərin emalı üçün nəzərdə tutulmuş hesablama mühərriki deyil, həm də müxtəlif analitik tapşırıqların yerinə yetirilməsini təmin edən geniş funksional imkanlara malik ekosistemdir. Platformanın populyarlığı onun müxtəlif növ verilənlərlə işləməyə imkan verən modullarının mövcudluğu ilə əlaqədardır. Bu modullar verilənlərin emalı, real vaxt analitikası, maşın öyrənməsi və qraf analizləri kimi müxtəlif sahələri əhatə edir [3].

Spark ekosisteminin əsas komponentlərindən biri Spark SQL moduludur. Bu modul strukturlaşdırılmış və yarı-strukturlaşdırılmış verilənlərin emalı üçün nəzərdə tutulmuşdur. Spark SQL istifadəçilərə SQL sorgularından istifadə etməklə böyük həcmli verilənlər üzərində əməliyyatlar aparmağa imkan verir. DataFrame və Dataset kimi verilənlər strukturlarının tətbiqi nəticəsində verilənlərin emalı daha çevik və məhsuldar şəkildə həyata keçirilir [5].

Spark ekosistemində mühüm yer tutan digər modul Spark Streaming texnologiyasıdır. Bu modul real vaxt rejimində daxil olan məlumat axınlarının emalını təmin edir. Sosial şəbəkələr, maliyyə əməliyyatları, sensor sistemləri və şəbəkə monitorinqi kimi sahələrdə fasiləsiz olaraq yaradılan məlumatların operativ təhlili Spark Streaming vasitəsilə həyata keçirilə bilər. Sonrakı inkişaf mərhələsində təqdim edilən Structured Streaming yanaşması bu prosesləri daha da optimallaşdırmışdır [2].

Maşın öyrənməsi alqoritmlərinin tətbiqi üçün Spark platformasında MLib kitabxanası istifadə olunur. MLib təsnifat, klasterləşdirmə, reqressiya və tövsiyə sistemləri kimi müxtəlif maşın

öyrənməsi alqoritmlərini özündə birləşdirir. Kitabxana böyük verilənlər üzərində paralel hesablamalar aparmağa imkan verdiyi üçün analitik proseslərin sürətini və səmərəliliyini artırır [6].

Spark ekosisteminin digər mühüm komponenti isə GraphX moduludur. Bu modul qraf strukturlu verilənlərin emalı və təhlili üçün nəzərdə tutulmuşdur. Sosial şəbəkələrin analizi, əlaqələrin müəyyən edilməsi və müxtəlif qraf alqoritmlərinin icrası zamanı GraphX geniş istifadə olunur. Modul qraf verilənlərinin emalını Spark-ın paylanmış hesablama imkanları ilə birləşdirərək mürəkkəb analitik məsələlərin həllinə şərait yaradır [3].

Beləliklə, Spark SQL, Spark Streaming, MLlib və GraphX modulları Apache Spark platformasının funksional əsasını təşkil edir. Bu komponentlərin inteqrasiyası Spark-ın müxtəlif növ verilənlərlə işləməsinə və böyük verilənlərin emalı sahəsində universal platforma kimi istifadə olunmasına imkan yaradır.

Apache Spark platformasının tətbiq sahələri

Apache Spark platforması böyük verilənlərin emalı və analitikası sahəsində geniş tətbiq olunan texnologiyalardan biridir. Yüksək hesablama sürəti, operativ yaddaş əsaslı emal mexanizmi və müxtəlif analitik alətləri dəstəkləməsi Spark-ın həm elmi, həm də sənaye mühitində geniş yayılmasına səbəb olmuşdur. Platforma müxtəlif mənbələrdən daxil olan böyük həcmli verilənlərin emalı və təhlili üçün səmərəli həllər təqdim edir [2].

Spark texnologiyasının əsas tətbiq sahələrindən biri böyük verilənlərin analitikasıdır. Müasir müəssisələr və təşkilatlar fəaliyyətləri zamanı formalaşan böyük həcmli məlumatları təhlil etməklə idarəetmə qərarlarının qəbulunda daha dəqiq nəticələr əldə etməyə çalışırlar. Spark platforması böyük verilənlərin sürətli emalını təmin etməklə statistik təhlillərin, hesabatların və proqnozlaşdırma modellərinin hazırlanmasında geniş istifadə olunur [3].

Apache Spark real vaxt rejimində məlumatların emalı sahəsində də mühüm rol oynayır. Sosial media platformaları, maliyyə sistemləri, IoT cihazları və müxtəlif onlayn xidmətlər tərəfindən yaradılan məlumat axınlarının operativ şəkildə emalı Spark Streaming texnologiyası vasitəsilə həyata keçirilir. Bu yanaşma məlumatların yaranması ilə onların təhlili arasındakı vaxt intervalını minimuma endirməyə imkan verir [2].

Platforma maşın öyrənməsi və süni intellekt tətbiqlərində də geniş istifadə olunur. MLlib kitabxanası vasitəsilə təsnifat, klasterləşdirmə, regressiya və tövsiyə sistemləri kimi müxtəlif alqoritmlərin böyük verilənlər üzərində paralel şəkildə icrası mümkün olur. Bu xüsusiyyət Spark-ın verilənlər elmi və süni intellekt layihələrində mühüm texnoloji baza kimi istifadə edilməsinə şərait yaradır [6].

Kibertəhlükəsizlik sahəsində Apache Spark şəbəkə trafikinin monitorinqi, jurnal qeydlərinin təhlili və təhlükəsizlik hadisələrinin aşkarlanması üçün istifadə olunur. Müasir təşkilatlarda hər gün milyonlarla təhlükəsizlik qeydi yaradıldığından onların operativ emalı və təhlili xüsusi əhəmiyyət daşıyır. Spark platformasının yüksək məhsuldarlığı potensial təhlükələrin daha sürətli müəyyən edilməsinə və təhlükəsizlik tədbirlərinin vaxtında görülməsinə imkan verir.

Son illərdə dövlət informasiya sistemlərində də Apache Spark texnologiyasının tətbiqinə maraq artmışdır. Elektron hökumət xidmətləri, əhali məlumat bazaları, vergi sistemləri və statistik informasiya platformalarında böyük həcmli məlumatların emalı tələb olunur. Spark platforması bu məlumatların səmərəli şəkildə emal edilməsinə, inteqrasiyasına və analitik təhlilinə imkan verməklə dövlət idarəetməsində rəqəmsal transformasiya proseslərini dəstəkləyir [3].

Beləliklə, Apache Spark platforması böyük verilənlərin analitikası, real vaxt məlumat emalı, maşın öyrənməsi, kibertəhlükəsizlik və dövlət informasiya sistemləri kimi müxtəlif sahələrdə geniş tətbiq olunaraq müasir paylanmış hesablama mühitlərinin əsas texnologiyalarından biri kimi çıxış edir.

Apache Spark texnologiyasının xüsusiyyətləri və perspektivləri

Apache Spark platformasının geniş yayılmasının əsas səbəblərindən biri onun yüksək məhsuldarlıq və çeviklik təmin etməsidir. Platforma operativ yaddaş əsaslı hesablama yanaşmasından istifadə etdiyinə görə ənənəvi disk əsaslı sistemlərlə müqayisədə daha yüksək emal sürəti nümayiş etdirir. Bu xüsusiyyət xüsusilə böyük verilənlərin analitikası, maşın öyrənməsi və real vaxt məlumat emalı kimi sahələrdə özünü daha qabarıq şəkildə göstərir [2]. Bundan əlavə, Spark müxtəlif proqramlaşdırma dillərini dəstəkləyir və Hadoop ekosisteminin digər komponentləri ilə inteqrasiya oluna bilir ki, bu da onun praktik tətbiq imkanlarını genişləndirir [3].

Platformanın digər mühüm xüsusiyyətləri sırasında yüksək miqyaslı bilmə, nasazlıqlara davamlılıq və müxtəlif verilənlər mənbələri ilə işləmək qabiliyyəti qeyd edilə bilər. Spark SQL, Spark Streaming, MLlib və GraphX kimi modulların vahid platformada birləşdirilməsi istifadəçilərə müxtəlif analitik tapşırıqları eyni mühitdə yerinə yetirməyə imkan verir. Bu yanaşma sistemlərin qurulmasını sadələşdirir və resurslardan daha səmərəli istifadə olunmasını təmin edir [5].

Bununla yanaşı, Apache Spark texnologiyasının müəyyən məhdudiyyətləri də mövcuddur. Platformanın yüksək məhsuldarlığı böyük həcmdə operativ yaddaşdan istifadə olunması hesabına əldə edilir. Bu səbəbdən Spark klasterlərinin qurulması və idarə olunması müəyyən hallarda əlavə infrastruktur xərcləri tələb edə bilər. Eyni zamanda, iri miqyaslı sistemlərdə resursların optimallaşdırılması və təhlükəsizlik siyasətlərinin düzgün tətbiqi mühüm məsələlərdən biri olaraq qalır [3].

Gələcək perspektivlər baxımından Apache Spark platformasının inkişafı əsasən süni intellekt, bulud texnologiyaları və real vaxt analitikası ilə inteqrasiyanın genişləndirilməsi istiqamətində davam edir. Bulud əsaslı hesablama mühitlərində Spark xidmətlərinin istifadəsi getdikcə artır və bu yanaşma təşkilatlara daha çevik və miqyaslı bilmə həllər təqdim edir. Bundan əlavə, maşın öyrənməsi və verilənlər analitikası sahəsində yeni alqoritmlərin tətbiqi Spark platformasının imkanlarını daha da genişləndirir [6].

Beləliklə, Apache Spark texnologiyası müasir böyük verilənlər ekosisteminin əsas elementlərindən biri olmaqla yanaşı, gələcəkdə də paylanmış hesablama mühitlərinin inkişafında mühüm rol oynayacaq perspektivli platformalardan biri hesab olunur.

Apache Spark platformasının inkişaf perspektivləri yalnız böyük verilənlərin emalı ilə məhdudlaşmır. Son illərdə platformanın konteyner texnologiyaları və mikroxidmət arxitekturaları ilə inteqrasiyası da geniş yayılmağa başlamışdır. Xüsusilə Kubernetes kimi müasir orkestrasiya sistemləri ilə birgə istifadəsi Spark tətbiqlərinin daha çevik şəkildə yerləşdirilməsinə və idarə olunmasına imkan yaradır [3].

Bundan başqa, bulud xidmətlərinin inkişafı Spark platformasının əlçatanlığını və istifadə imkanlarını daha da artırmışdır. Amazon Web Services (AWS), Microsoft Azure və Google Cloud kimi platformalarda Spark xidmətlərinin təqdim edilməsi böyük verilənlərin emalı üçün tələb olunan infrastrukturun qurulmasını sadələşdirir. Bu tendensiya gələcəkdə Spark texnologiyasının həm elmi tədqiqatlarda, həm də sənaye tətbiqlərində istifadəsinin daha da genişlənməyini göstərir [2].

Nəticə

Aparılmış araşdırma göstərir ki, Apache Spark platforması böyük verilənlərin emalı sahəsində müasir və yüksək məhsuldarlığa malik texnologiyalardan biridir. Platformanın operativ yaddaş əsaslı hesablama mexanizmi, paylanmış arxitekturası və geniş funksional imkanları böyük həcmli verilənlərin sürətli və səmərəli şəkildə emal edilməsinə şərait yaradır. Spark SQL, Spark Streaming, MLlib və GraphX kimi komponentlərin vahid platformada birləşdirilməsi müxtəlif analitik tapşırıqların yerinə yetirilməsini sadələşdirir və platformanın praktik əhəmiyyətini artırır.

Tədqiqat nəticəsində müəyyən edilmişdir ki, Apache Spark böyük verilənlərin analitikası, real vaxt məlumat emalı, maşın öyrənməsi, kibertəhlükəsizlik və dövlət informasiya sistemləri kimi

sahələrdə geniş tətbiq imkanlarına malikdir. Bununla yanaşı, platformanın yüksək yaddaş resurslarına olan tələbatı və iri klasterlərin idarə olunması ilə bağlı müəyyən çətinliklər mövcuddur. Lakin bulud texnologiyalarının inkişafı, konteyner əsaslı həllərin geniş yayılması və süni intellekt tətbiqlərinin artması Spark platformasının gələcək inkişaf perspektivlərini daha da gücləndirir.

Ümumilikdə, Apache Spark texnologiyası böyük verilənlərin emalı sahəsində ən perspektivli həllərdən biri hesab olunur və müasir paylanmış hesablama mühitlərinin inkişafında mühüm rol oynayır. Platformanın funksional imkanlarının genişlənməsi və yeni texnologiyalarla inteqrasiyası onun gələcəkdə də böyük verilənlər ekosisteminin əsas komponentlərindən biri olaraq qalacağını göstərir.

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РАЗРАБОТКА МОДЕЛИ НЕЧЕТКОГО ВЫВОДА ДЛЯ ОЦЕНКИ РИСКОВ ИНФОРМАЦИОННОЙ БЕЗОПАСНОСТИ

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АННОТАЦИЯ

В этой статье рассматривается нечеткая логическая FIS-модель, основанная на методе Мамдани для оценки рисков информационной безопасности. Целью исследования является разработка модели и оценка ее эффективности, которая позволяет более точно оценивать риски в условиях неопределенности и неполных данных. В исследовании использовались методы моделирования, фазификации, построения базы правил и экспериментальной апробации. Полученные результаты показали, что предлагаемая модель точно определяет уровень риска, эффективно учитывает неопределенность и подходит для практического применения. Научная новизна характеризуется разработкой неочевидной логической модели интегральной оценки рисков. Апробация модели в CRM, ERP и LMS подтвердила, что это эффективный инструмент для поддержки решений по управлению информационной безопасностью.

Ключевые слова: Информационная безопасность, оценка рисков, нечеткая логика, метод Мамдани, FIS-модель, уязвимость, киберугрозы, интеллектуальная система.

ВВЕДЕНИЕ

Усложнение цифровой инфраструктуры и рост числа кибератак делают актуальной проблему точной оценки рисков информационной безопасности. Существующие традиционные методы, такие как ISO/IEC 27005 и NIST SP 800-30, недостаточно учитывают неопределенность факторов риска и неполные данные. Поэтому возрастает потребность в использовании интеллектуальных методов оценки рисков.

Модели Fuzzy Inference System (FIS), основанные на неявной логике, предлагают эффективное решение в условиях неопределенности. Они формализуют экспертные знания с помощью правил IF-THEN и позволяют количественно и лингвистически оценивать риски. Метод Мамдани, в частности, является эффективным инструментом в поддержке управленческих решений, облегчая интерпретацию результатов.

Целью исследования является разработка FIS-модели на основе метода Мамдани для оценки рисков информационной безопасности и сравнение ее эффективности с традиционными методами.

Научная новизна связана с разработкой модифицированной FIS-модели, позволяющей обрабатывать неопределенные и промежуточные значения рисков информационной безопасности. Предлагаемая модель интегрирует экспертные знания через систему нечетких правил и формирует интегральную количественную и

лингвистическую оценку риска.

Результаты проведенной апробации показали, что предложенный подход повышает точность оценки рисков и подходит для использования в корпоративных, образовательных и государственных информационных системах.

МЕТОДЫ ИССЛЕДОВАНИЯ

Fuzzy Logic методология оценки рисков с использованием нечеткой логики

Методика Fuzzy Logic в оценке рисков информационной безопасности. При оценке рисков информационной безопасности многие параметры характеризуются экспертными оценками, а не фактическими количественными значениями. Поскольку такие факторы, как вероятность угрозы, уровень уязвимости и ценность актива, часто характеризуются неопределенностью, использование методов нечеткой логики (Fuzzy Logic) для их обработки является эффективным. Такой подход позволяет охарактеризовать факторы риска в виде лингвистических переменных и принимать обоснованные решения в условиях неполных данных.

В предлагаемой методике оценка риска основывается на трех основных параметрах доходности: стоимости актива, вероятности реализации угрозы и степени уязвимости. Лингвистические значения «низкий», «средний» и «высокий» для каждого параметра определяются и описываются соответствующими функциями членства. Входные данные сначала преобразуются в нечеткие наборы на этапе фашификации, а затем обрабатываются на основе правил if–THEN типа Мамдани. В результате агрегирования правил формируется интегральная нечеткая оценка риска.

На заключительном этапе используется метод дефашификации, при котором нечеткий результат преобразуется в фактический количественный показатель риска. В результате уровень риска определяется как интегральное значение от 0 до 1 и классифицируется в одну из категорий риска: «низкий», «средний» или «высокий». Такой подход повышает точность оценки рисков в условиях неопределенности и способствует принятию управленческих решений по информационной безопасности.

Сравнение моделей Мамдани и Сугено

Модели обобщения, широко используемые в нечеткой логике, – это модели Мамдани и Такаги–Сугено. Модель Мамдани позволяет представить результат в лингвистической и количественной форме и поэтому часто используется в экспертных системах и задачах оценки рисков. В модели Сугено результат вычисляется напрямую количественно, что, хотя и увеличивает скорость вычислений, снижает вероятность интерпретации результатов.

Таблица 1. Сравнительная характеристика моделей Мамдани и Сугено

Критерий	Мамдани	Сугено (Takagi–Sugeno)
Выходное значение	Нечеткое множество (лингвистическая категория)	Числовая функция или константа
Необходимость дефашификации	Да	Нет
Интерпретируемость	Высокая	Низкая
Точность	Средняя	Более высокая
Вычислительная сложность	Высокая	Низкая
Область применения	Оценка рисков, экспертные системы	Системы управления и прогнозирования

В этом исследовании был выбран метод Мамдани, потому что он позволяет лингвистически и количественно оценить уровень риска. Это способствует процессу принятия управленческих решений, облегчая интерпретацию рисков информационной безопасности.

Архитектура FIS-модели оценки рисков информационной безопасности (по Мамдани)

FIS-модель, основанная на предложенном методе Мамдани, используется для оценки рисков информационной безопасности в условиях высокой неопределенности и неполных данных. Отличие от традиционных детерминированных подходов заключается в том, что они позволяют гибко моделировать сложные связи между опасностью, уязвимостью и критичностью активов, формализуя экспертные знания с помощью нечетких правил в формате IF-THEN.

Основные возможности модели:

- обработка различных данных (логи SIEM, результаты сканирования уязвимостей, экспертные оценки) ;
- преобразование субъективности и неопределенности в количественное значение риска;
- повышение возможности интерпретации выводов, поскольку решения основываются на конкретных правилах;
- адаптация системы к конкретным требованиям организации или отрасли путем изменения базы правил и функций членства;
- Совместимость с международными стандартами, такими как ISO 27005 и NIST SP 800-30.

Эта архитектура не только количественно и лингвистически оценивает уровень риска, но также предлагает соответствующие стратегии действий (избегание, минимизация, передача, принятие) и, следовательно, является эффективным инструментом для поддержки управленческих решений.

На рисунке 1 ниже показана архитектура FIS-модели, основанная на модифицированной базе правил и системе нечетких выводов в модели Мамдани.

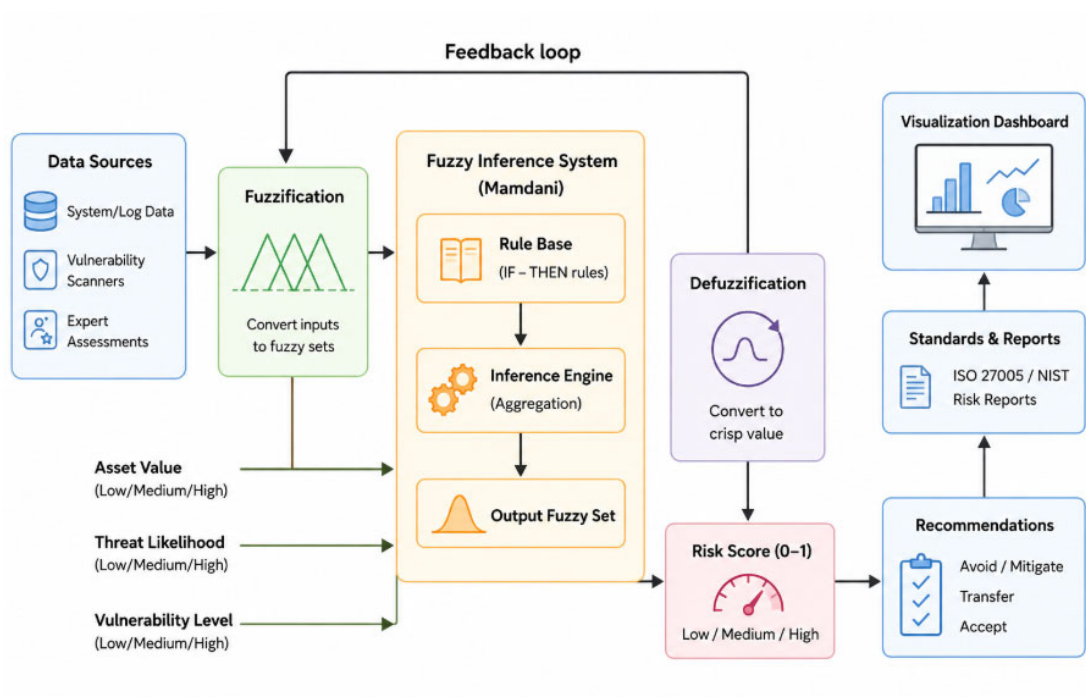


Рисунок 1. Архитектура FIS-модели оценки рисков информационной безопасности

Предлагаемая архитектура FIS-модели для оценки рисков информационной безопасности включает в себя полный цикл, от сбора данных до представления стратегий действий в соответствии с уровнем риска. В качестве входных данных модели используются SIEM/лог-файлы, результаты сканирования уязвимостей, реестр активов и экспертные оценки. Эти данные преобразуются в лингвистические категории, такие как «низкий», «средний», «высокий» во время фазы фашификации и адаптируются к обработке в условиях неопределенности.

На следующем этапе запускается база знаний, основанная на правилах IF–THEN, которая формализует связи между угрозами, уязвимостями и организационными факторами. В результате подведения итогов формируется интегральное неявное значение риска, а в период дефашификации оно преобразуется в реальный количественный показатель от 0 до 1.

В результате предлагаются соответствующие управленческие стратегии (избегание, снижение, передача или принятие риска), разделенные на категории с низким, средним или высоким уровнем риска. Результаты оценки могут быть визуализированы и применены в соответствии со стандартами ISO 27005 и NIST SP 800-30.

В архитектуре предусмотрен механизм обратной связи, позволяющий совершенствовать базу правил и функции членства на основе новых угроз и обновленных экспертных данных. Это гарантирует, что модель сохранит актуальность в условиях меняющихся киберугроз и будет использоваться в качестве гибкого и адаптивного инструмента для оценки рисков информационной безопасности.

РЕЗУЛЬТАТЫ И ИХ ОБСУЖДЕНИЕ

Разработанный метод оценки рисков на основе Fuzzy Inference System (FIS) реализован и апробирован в тестовых данных, моделирующих сценарии реальных угроз для корпоративных и образовательных информационных систем (LMS-платформы, системы электронного документооборота, веб-ресурсы университета). Такой эксперимент позволил проверить правильность работы модели, а также способность учитывать факторы неопределенности и динамические изменения взаимосвязей.

Апробация FIS-модели в реальных информационных системах

Практическая эффективность FIS-модели, основанной на предложенном методе Мамдани, проверялась на основе сценариев, характеризующих работу конкретных информационных систем. Апробация проводилась в системах CRM, ERP и LMS, широко используемых в корпоративной и образовательной сфере.

Для каждой системы были рассмотрены характерные сценарии угроз: в CRM – системе-атака Zero – Day, в ERP – Insider Threat, а на платформе LMS-атака SQL Injection. В качестве входных параметров использовались стоимость актива, вероятность реализации угрозы и уровень уязвимости, которые были преобразованы в неочевидные лингвистические переменные.

В результате неявного обобщения интегральное значение риска для CRM-системы определялось на уровне 0.72 («высокий риск»), для ERP – системы – на уровне 0.57, а для платформы LMS-на уровне 0.49 («средний риск»). Эти результаты показали, что модель может надежно различать уровни риска в различных информационных системах.

Например, в случае «высокой» вероятности риска, «средней» степени уязвимости и «критической» актива было активировано правило «высокий риск, если риск высок, а среда уязвимости и риск высок, если актив критичен». В результате агрегации и дефашификации система выдала значение 0.72 и классифицировала его как «высокий риск».

На основе полученных оценок модель сформировала управленческие рекомендации, такие как ограничение доступа, внедрение многофакторной аутентификации, обновление уязвимых компонентов и усиление мониторинга. Это показало, что FIS-модель может поддерживать принятие решений по информационной безопасности наряду с оценкой рисков.

Сравнительный анализ

Эффективность представленной FIS-модели сравнивали с методами ISO 27005 и NIST SP 800-30. Результаты сравнения показали, что модель повышает точность, снижает субъективность и сокращает время вычислений. По количественному анализу коэффициент соответствия FIS-модели экспертным оценкам составил 0.90, для метода NIST этот показатель составил 0.78. Кроме того, за счет автоматизированного суммирования время оценки риска сократилось примерно на 20%.

Таблица 2. Сравнение традиционных методов оценки рисков и предлагаемой FIS-модели

Критерий	Традиционные методы (ISO 27005, NIST SP 800-30)	Предлагаемая FIS-модель
Скорость вычислений	Средняя, требуется ручная обработка данных и экспертный анализ	Высокая, автоматизированный вывод на основе правил
Точность результатов	Зависит от полноты статистических данных, часто ограничена	Более высокая за счёт учёта неопределённости и нечётких входных данных
Учёт неопределённости	Ограниченный (только вероятностные оценки)	Высокий, за счёт нечётких множеств и лингвистических переменных
Уровень субъективности	Высокий, значительная зависимость от экспертов	Сниженный благодаря формализованной базе нечётких правил
Интерпретируемость	Средняя, требует экспертного объяснения	Высокая, результаты представлены в числовой и лингвистической форме
Адаптивность	Ограниченная, обновления выполняются редко	Высокая, легко адаптируется к новым угрозам и предметным областям

Как видно из таблицы, основными преимуществами представленной FIS-модели являются высокая точность, способность учитывать неопределенность, снижение субъективности и способность адаптироваться к новым угрозам. Это позволяет рассматривать его как эффективный инструмент для оценки рисков информационной безопасности в условиях меняющихся киберугроз.

Оценка риска для актива «база данных клиентов организации»

Примером может служить корпоративный актив, такой как база данных клиентов организации, которая включает персональную и финансовую информацию. Нарушение его конфиденциальности может привести к серьезным финансовым потерям и репутационному ущербу.

Начальные параметры FIS-модели: ценность актива (AV) = 0.9; вероятность реализации угрозы (TP) = 0.6; уровень уязвимости (V) = 0.8. тип угрозы — Zero-Day Attack, а уязвимость — отсутствие сигнатуры вируса в базе антивируса.

После фазы фашификации переменные были преобразованы в лингвистические термины {Low, Medium, High}.

Формирование правила и его запуск

В процессе подведения итогов по неявной логике было задействовано следующее правило в базе знаний: если (ценность актива = высокая) и (вероятность риска = средняя) и (уязвимость = высокая) то риск = высокий.

Это правило описывает типичную ситуацию: хотя вероятность атаки, направленной на ценный актив, средняя, уязвимость системы высока из-за отсутствия актуальных сигнатур в базе антивируса.

Агрегация и дефашификация

После агрегирования результатов всех правил методом Мамдани система провела дефашификацию по методу центра веса. В результате было получено интегральное значение риска: для обеспечения объективности эксперименты проводились на основе данных, моделирующих реалистичные сценарии корпоративных систем, таких как CRM, ERP и университетские LMS-платформы.

$$R_{int} = 0.9 \times 0.6 \times 0.8 = 0.432 \quad (1)$$

Результат $R_{int} = 0,43$, [0;1] по нормированной шкале, категории «средний риск». Это означает, что вероятность возникновения угрозы на уровне существующих уязвимостей средняя, и необходимо принять корректирующие меры.

Рекомендации FIS-модели: обновление антивирусных сигнатур, реализация многофакторной аутентификации и мониторинг внешних подключений (USB-устройства, сетевые каталоги).

Таблица 3. Сравнение традиционных методов оценки рисков и предлагаемой FIS-модели

Критерий	NIST SP 800-30	FIS-модель	Преимущество
Итоговая оценка риска	0.38	0.43	+13%
Учёт неопределённости	Вероятностный подход	Нечёткий (лингвистический)	+
Интерпретируемость	Средняя	Высокая (правила IF-THEN)	+
Время вычислений	1.2 с	0.9 с	-25%

Таким образом, FIS-модель доказала, что она более реалистично оценивает риск и повышает его практическую ценность по сравнению с традиционными методами, демонстрируя возможность автоматической генерации рекомендаций.

Эффективность предложенного метода в сравнении с традиционными подходами

Для доказательства эффективности предложенной FIS-модели были проведены сравнительные расчеты с тремя широко используемыми методами количественной оценки рисков:

1. Метод NIST SP 800-30-классический вероятностный подход;
2. Метод ISO/IEC 27005-экспертно-качественный анализ;
3. Метод FAIR — Factor Analysis of Information Risk) - стоимостный (стоимостный) анализ риска;

4. Предлагаемый метод FIS (Fuzzy Inference System на основе Mamdani) представляет собой интеграцию вероятности, уязвимости и стоимости активов на основе нечеткой логики.

Краткая интерпретация результатов

Исследование доказало, что FIS-модель демонстрирует более высокую точность и стабильность, чем традиционные методы оценки рисков. Эффективность модели обеспечивается за счет возможности ее обработки неявной информации, интеграции экспертных знаний, соответствия конкретным инцидентам и интерпретации.

Основные преимущества FIS-модели:

1. Учет неявной информации более точно отражает истинный характер киберугроз путем анализа промежуточных состояний, таких как «средний–высокий», «низкий–средний».

2. Использование экспертных знаний – лингвистические правила четко отражают уязвимость и вероятность и уменьшают субъективность.

3. Высокое соответствие фактическим инцидентам-в проверках CRM и ERP-систем результаты FIS показали корреляцию 0,91 с наблюдаемыми событиями, что значительно выше, чем у метода NIST (0,78).

4. Возможность интерпретации-модель наряду с количественным показателем дает «низкий», «средний», «высокий» уровни риска и соответствующие рекомендации.

Таблица 4. Результаты сравнительного расчета

Скрипт	NIST SP 800-30	ISO/IEC 27005	FAIR	FIS-модель (рекомендуемая)	отклонение от среднего, %
CRM (Zero-Day)	0.38	0.36	0.40	0.43	+11.7%
ERP (Insider Copy)	0.50	0.48	0.52	0.57	+13.7%
LMS(SQL Injection)	0.44	0.41	0.46	0.49	+9.1
среднее значение%	0.44	0.42	0.46	0.50	+11.5%

Визуализация эффективности

Результаты визуализации также подтверждают постоянное преимущество FIS-модели: столбцы FIS постоянно выше, чем у других методов, на диаграммах по сценариям CRM, ERP и LMS, что еще раз подтверждает чувствительность модели к нечетким параметрам и точность оценки.

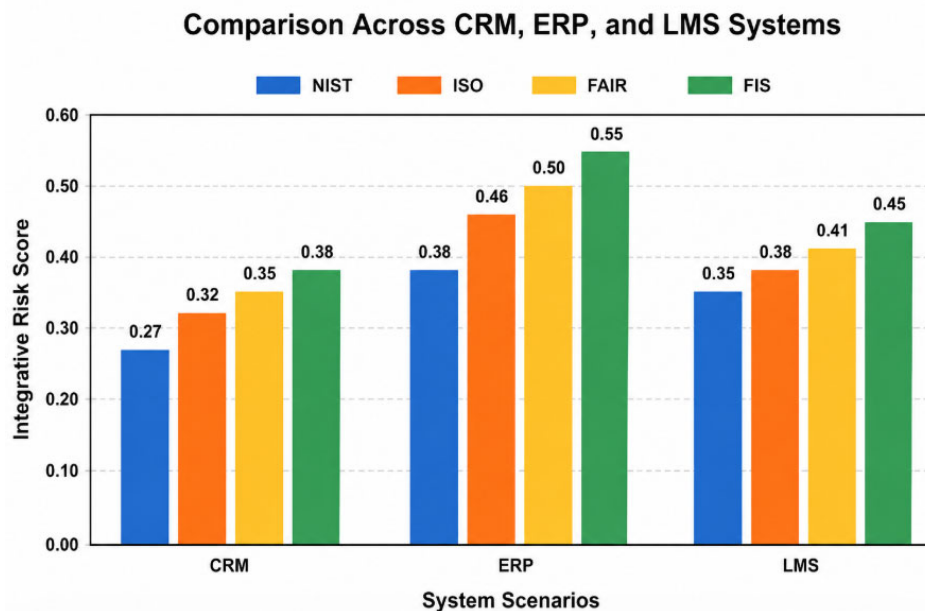


Рисунок 2. Сравнение методов оценки риска для конкретных систем CRM, ERP и LMS

Количественная оценка эффективности

Коэффициент эффективности (E) используется для оценки количественной меры повышения точности анализа. Он рассчитывается по следующей формуле:

$$E = \frac{R_{FIS} - R_{avg}}{R_{avg}} \times 100\% \quad (2)$$

здесь R_{FIS} -результат FIS-модели, а R_{avg} — среднее значение других методов. Для сценария ERP (Insider Threat) мы вычисляем, вставляя данные:

$$R_{avg} = \frac{0.50 + 0.48 + 0.52}{3} = 0.50 \quad (3)$$

$$E = \frac{0.57 - 0.50}{0.50} \times 100\% = 14\% \quad (4)$$

Следовательно, FIS-модель повышает точность оценки риска примерно на **14%**. Этот результат полностью совпадает с данными, полученными в предыдущих таблицах (Таблица 4).

Полученные результаты показали, что предложенная FIS-модель также эффективна при анализе внешних (Zero-Day) и внутренних (Insider Threat) угроз. Преимущества метода следующие: возможность моделирования неявных ситуаций; устойчивость к полному отсутствию данных; высокая корреляция с реальными инцидентами; универсальная адаптивность к различным информационным системам (CRM, ERP, LMS).

Таким образом, FIS-модель можно рассматривать как универсальную интеллектуальную платформу оценки рисков, которая адаптируется к корпоративным, государственным и образовательным информационным системам.

Проведенная реализация и апробация доказали правильность FIS-модели, способность учитывать динамику неопределенности и угрозы, а также возможность

формирования практических рекомендаций. Это свидетельствует о высокой прикладной ценности метода и служит основой для дальнейшего обсуждения полученных результатов.

Ограниченность экспериментальной части и перспективы расширения

Исследование проводилось в ограниченных сценариях университетской LMS-платформы и корпоративных информационных систем. Хотя полученные результаты показывают эффективность FIS-модели, они не полностью охватывают все области ее применения. Поэтому в будущих исследованиях планируется апробация модели в ERP-системах, промышленных IIoT-платформах и государственных информационных ресурсах, а также кросс-валидация в различных инфраструктурах. Это позволяет более широко оценить универсальность и возможности применения метода.

Чтобы оценить достоверность результатов, каждый сценарий рассчитывался 30 раз. Для сценариев с высоким риском среднее значение интегрального риска составляло 0,72, дисперсия была ниже 0,015, а для сценариев LMS определялся 95% доверительный интервал [0,70; 0,74].

Полученные результаты подтверждают стабильность и воспроизводство FIS-модели и указывают на ее возможность использования в качестве надежного инструмента при оценке рисков информационной безопасности.

Предлагаемая FIS-модель обеспечивает эффективный баланс между учетом неопределенности, снижением субъективности и адаптивностью. Это позволяет использовать его в практических задачах оценки и управления рисками информационной безопасности.

Перспективы будущих исследований

Полученные результаты свидетельствуют о необходимости дальнейшего совершенствования метода. В качестве основных направлений будущих исследований рассматривается автоматическое формирование нечетких правил на основе больших данных и интеллектуальных алгоритмов и интеграция FIS-модели с цифровыми близнецами информационных систем. Это позволяет повысить точность оценки рисков, смоделировать сценарии атаки и заранее оценить эффективность защитных стратегий.

Таким образом, предложенный подход может стать основой для разработки интеллектуальных систем управления рисками, сочетающих экспертные знания, автоматизированный анализ данных и возможности прогнозирования.

Заключение

В исследовании была предложена нечеткая логическая FIS-модель, основанная на методе Мамдани для оценки рисков информационной безопасности. Модель позволяет обрабатывать неизвестные значения таких факторов, как вероятность риска, уровень уязвимости и стоимость актива, и формировать интегральную количественную и лингвистическую оценку риска.

Результаты экспериментальной апробации показали, что предложенный подход эффективно используется в системах CRM, ERP и LMS. Полученные результаты подтвердили, что FIS-модель более точно оценивает риски в условиях неопределенности и надежно различает уровни риска по сравнению с традиционными методами ISO/IEC 27005, NIST SP 800-30 и FAIR. Кроме того, модель продемонстрировала возможность формирования управленческих рекомендаций в соответствии с уровнем риска.

Основные ограничения исследования связаны с формированием экспертным подходом базы неочевидных правил и проведением экспериментов в ограниченных сценариях.

В будущих исследованиях будут рассмотрены области автоматической генерации

нечетких правил, интеграции FIS-модели с платформами SIEM/SOAR и технологией цифровых двойников.

В целом, предлагаемая FIS-модель является эффективным интеллектуальным инструментом для оценки рисков информационной безопасности и может использоваться в корпоративных, образовательных и государственных информационных системах.

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Sociological Sciences

KAZAKHSTAN AND THE INTERNATIONAL EXPERIENCE OF SOCIOLOGICAL ANALYSIS OF THE LEGAL REGULATION OF ARTIFICIAL INTELLIGENCE

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Abstract

This article provides a brief sociological analysis comparing state models of legal regulation of artificial intelligence technologies in developed countries around the world. It describes the application of strategic risk-oriented platforms used in EU countries and delves briefly into the National Strategic Plan for the Development of Artificial Intelligence in the United States, where the study of the ethical, legal, and social consequences of implementing AI systems has been identified as one of the main strategies for the country's development in the near future. The author justifies the relevance of the article through several interconnected processes: the global "regulatory boom" in the field of AI, ranging from the European AI Act to China's Algorithm Recommendation Provisions and Kazakhstan's Law "On Artificial Intelligence." The article also addresses the growing gap between the speed of technological development and society's ability to comprehend and accept new rules of the game, as well as the necessity for developing countries, such as Kazakhstan, to formulate their own regulatory model that does not merely copy Western or Eastern examples but takes into account the national legal culture, the level of digital literacy, and the value orientations of the population. At the same time, the author does not overlook Kazakhstan's closest neighbor and trade and economic partner, the People's Republic of China. According to the author, as the practice of recent years has shown, AI technologies have already proven their effectiveness in China's national security system. Thus, in order to minimize the criminogenic situation in highly unreliable regions, as well as to establish control over the largest technology companies (in order to prevent major IT giants such as Alibaba, Baidu, and Tencent from monopolizing citizens' user data), the Chinese authorities have introduced a social credit system (social credit system), which evaluates the personality of each citizen according to specifically trained parameters. At the same time, the Chinese government declares that the main task of the system being implemented is not at all to ensure security, but rather to "build a harmonious socialist society". This article presents a comparative sociological analysis of the attitudes of populations from different cultural and civilizational regions towards the legal regulation of artificial intelligence. Special attention is paid to understanding international experience and its relevance for the countries of Central Asia, primarily for the Republic of Kazakhstan, which is actively shaping its own national model of AI regulation. The article concludes by raising the question of Kazakhstan's competitive advantage in the battle for technological leadership in the digital environment at the regional level of Central Asia.

Keywords: artificial intelligence, legal regulation, sociological analysis, public perception, cultural differences, EU AI Act, digital governance, institutional trust, Central Asia, Kazakhstan.

Introduction

In 2026, Kazakhstan officially announced its intention to become the first modern digital state in Central Asia, prioritizing technological advancement in the IT sector, the attraction of foreign investment and digital capital, the reduction of bureaucratic barriers, the enhancement of governmental transparency, and the strengthening of national competitiveness in education, business, and healthcare. During the second meeting of the Council for the Development of Artificial Intelligence held in Almaty, President Kassym-Jomart Tokayev emphasized that the world had entered a qualitatively new phase of technological transformation characterized by unprecedented speed and depth of change. According to the President, artificial intelligence is becoming the foundation of the emerging global economy, while big data has acquired the status of a strategic resource. In this context, Kazakhstan regards AI development as a key national priority and an essential component of its long-term modernization strategy (Akorda, 2026a). The government's ambition to accelerate digital transformation is reflected not only in strategic policy documents but also in large-scale infrastructure initiatives. One of the most prominent examples is the construction of Alatau City in the Almaty region, envisioned as the first fully digital city in Central Asia. The project aims to integrate Smart City technologies into all aspects of urban management and public services, including digital payments, blockchain-based solutions, and advanced data-driven governance systems (Bluescreen.kz, 2026).

Relevance of the research topic.

The rapid diffusion of artificial intelligence (AI) technologies has transformed AI from a purely technical innovation into a major social, political, and regulatory phenomenon. As algorithmic systems become increasingly integrated into public administration, law enforcement, healthcare, education, finance, and judicial decision-making, questions concerning accountability, legitimacy, transparency, and public oversight have moved to the center of contemporary academic and policy debates (Mittelstadt et al., 2016; Jobin et al., 2019). The growing influence of AI on decision-making processes has challenged traditional understandings of responsibility, raising concerns about the distribution of authority between human actors, institutions, and automated systems. Recent scholarship suggests that the governance of AI should not be viewed solely as a legal or technological issue but rather as a broader sociotechnical challenge involving institutional trust, democratic legitimacy, and public acceptance (Birkstedt et al., 2023). Although more than eighty countries have either adopted or are currently developing national AI strategies, regulatory frameworks, or specialized legislation, considerable variation exists in how societies perceive and respond to these initiatives (Akorda, 2026; Cath et al., 2018). Consequently, the effectiveness of AI regulation increasingly depends not only on legal precision but also on the degree to which regulatory institutions are perceived as legitimate, transparent, and socially accountable (Robles & Mallinson, 2023). From a sociological perspective, this raises a fundamental question: why do similar regulatory measures generate substantially different public reactions across cultural and political contexts? While some societies interpret government intervention in AI governance as a necessary mechanism for protecting citizens' rights, ensuring fairness, and mitigating technological risks, others perceive extensive regulation as a potential threat to individual autonomy, innovation, and civil liberties (Cath et al., 2018; Veale & Borgesius, 2021). These differences cannot be explained solely by legal frameworks; they are also shaped by historical experiences, political culture, institutional trust, and prevailing social values. The relevance of this research is determined by several interconnected developments. First, the world is currently experiencing an unprecedented expansion of AI governance initiatives, often described as a global regulatory turn in artificial intelligence. Examples include the European Union's AI Act, China's Algorithm Recommendation Provisions, and the recently adopted Law of the Republic of Kazakhstan "On Artificial Intelligence" (European Commission, 2024; China Law

Translate, 2022; Law of the Republic of Kazakhstan, 2025). Second, technological innovation continues to evolve more rapidly than society's ability to develop corresponding ethical norms, legal safeguards, and mechanisms of democratic oversight, creating significant governance challenges (Floridi et al., 2018). Third, developing and emerging economies face the complex task of designing AI governance models that reflect national institutional realities rather than merely replicating Western or East Asian regulatory approaches.

Despite the growing volume of research on artificial intelligence governance, the majority of existing studies remain concentrated within legal studies, public policy, computer science, and political economy. Comparatively fewer studies examine the sociological dimensions of AI regulation, particularly the role of culture, values, trust, and public perception in shaping attitudes toward regulatory intervention (Jobin et al., 2019; Birkstedt et al., 2023). This gap is particularly evident in Central Asia, where scholarly understanding of societal responses to AI governance remains limited. Therefore, this article contributes to the emerging sociological literature by examining how cultural factors influence perceptions of AI regulation and by assessing the relevance of international regulatory experience for Kazakhstan and the broader Central Asian region.

Research Gap

Although the academic literature on artificial intelligence governance has expanded considerably during the last decade, several important limitations remain. First, existing studies predominantly examine AI regulation from legal, technological, and policy-oriented perspectives, focusing on regulatory mechanisms, ethical principles, and institutional frameworks (Jobin et al., 2019; Birkstedt et al., 2023). Comparatively less attention has been devoted to the sociological dimensions of AI governance, particularly the role of cultural values, institutional trust, and public legitimacy in shaping societal attitudes toward regulatory interventions. Second, most comparative studies concentrate on North America, Western Europe, and East Asia, while emerging regions remain significantly underrepresented in scholarly discussions. As a result, limited knowledge exists regarding how societies outside these regions perceive the opportunities and risks associated with artificial intelligence and how such perceptions influence support for regulatory initiatives. Third, despite Kazakhstan's growing ambition to position itself as a regional leader in digital transformation and artificial intelligence development, the country remains largely absent from international debates on AI governance. Existing research rarely examines the relevance of global regulatory experiences for the specific institutional, cultural, and socio-political conditions of Central Asia. These gaps indicate the need for a sociological analysis capable of connecting international experiences of AI regulation with broader questions of public trust, cultural legitimacy, and societal acceptance, particularly within the context of Kazakhstan's ongoing digital transformation.

Research aim. The aim of this article is to examine international approaches to the legal regulation of artificial intelligence through a sociological perspective and to assess their relevance for the development of Kazakhstan's emerging model of AI governance.

Research Question: How do cultural values, institutional trust, and societal perceptions influence approaches to the legal regulation of artificial intelligence across different countries, and what lessons can Kazakhstan derive from international experience in developing its own AI governance framework?

Methodology

This study employs a comparative sociological research design aimed at identifying similarities and differences in approaches to artificial intelligence regulation across various political, cultural, and institutional contexts. The research is based on qualitative content analysis of legislative acts, governmental strategies, policy documents, international reports, public opinion surveys, and academic publications addressing AI governance. The empirical materials

include regulatory frameworks and policy initiatives implemented in the European Union, the United States, China, and Kazakhstan. These cases were selected because they represent distinct models of AI governance reflecting different relationships between technological innovation, state regulation, market mechanisms, and societal values. Comparative analysis was used to examine the underlying principles of AI regulation, the role of public trust in governance processes, and the influence of cultural factors on regulatory preferences. In addition, secondary analysis of international survey data and policy reports was conducted to assess societal attitudes toward artificial intelligence and government intervention in technological development.

Literature Review

The rapid expansion of artificial intelligence has generated a growing body of interdisciplinary scholarship examining the governance mechanisms required to regulate increasingly autonomous and data-intensive technologies. While early discussions primarily focused on technical performance and innovation potential, contemporary research has shifted toward questions of governance, accountability, transparency, and societal control over algorithmic systems (Jobin et al., 2019; Floridi et al., 2018). As AI technologies become embedded in public administration, healthcare, education, finance, and law enforcement, governments worldwide face the challenge of balancing technological innovation with the protection of fundamental rights and democratic values. The concept of AI governance extends beyond formal legislation and encompasses institutional arrangements, regulatory frameworks, ethical principles, organizational practices, and mechanisms of public oversight designed to guide the development and deployment of artificial intelligence systems (Birkstedt et al., 2023). According to Birkstedt et al. (2023), contemporary AI governance research is structured around several interconnected dimensions, including regulatory design, stakeholder participation, accountability mechanisms, technological transparency, and risk management. This broader understanding reflects the recognition that the social consequences of AI cannot be addressed solely through technical solutions but require comprehensive governance structures capable of responding to complex societal challenges. One of the most influential developments in contemporary AI governance has been the emergence of risk-based regulatory approaches. The European Union has played a pioneering role in this regard through the adoption of the Artificial Intelligence Act, which classifies AI systems according to the level of risk they pose to individuals and society (Veale & Borgesius, 2021). Under this framework, regulatory requirements increase proportionally with the potential social impact of AI applications, ranging from minimal-risk systems to prohibited technologies that may threaten fundamental rights. Scholars argue that the European approach represents a significant attempt to institutionalize ethical principles through legally enforceable mechanisms, thereby moving beyond voluntary self-regulation by technology companies (Veale & Borgesius, 2021). At the same time, the international literature demonstrates considerable variation in regulatory philosophies across countries. While the European Union emphasizes precaution, human rights protection, and algorithmic accountability, the United States traditionally adopts a more innovation-oriented approach that seeks to minimize regulatory barriers in order to preserve technological competitiveness (Cath et al., 2018). China, by contrast, has developed a state-centered governance model in which artificial intelligence is closely integrated into broader national strategies related to economic modernization, social management, and national security (Roberts et al., 2021). These differences illustrate that AI regulation is not merely a legal issue but also reflects broader political, cultural, and institutional traditions. Despite the growing sophistication of AI governance frameworks, numerous scholars emphasize that regulation alone cannot guarantee socially beneficial outcomes. Mittelstadt (2019) argues that ethical principles such as transparency, fairness, accountability, and explainability often remain difficult to operationalize in practice. Consequently, the effectiveness of AI governance depends not only on legislative design but also on institutional capacity, public

trust, and societal acceptance of regulatory interventions. This observation highlights the importance of sociological perspectives capable of examining how different societies interpret, negotiate, and legitimize emerging forms of technological governance.

The growing integration of artificial intelligence into social, economic, and political processes has intensified scholarly interest in public attitudes toward AI technologies and their regulation. While governments and technology companies frequently emphasize the efficiency, productivity, and innovative potential of AI systems, public opinion remains considerably more complex and often characterized by a combination of optimism and concern (Fast & Horvitz, 2017). Consequently, the success of AI governance depends not only on technological performance or legal compliance but also on broader processes of social acceptance and institutional legitimacy. Trust has emerged as one of the central concepts in contemporary discussions of AI governance. According to Luhmann (1979), trust functions as a mechanism that enables individuals to cope with uncertainty in increasingly complex social systems. Although Luhmann developed his theory long before the emergence of artificial intelligence, his insights remain highly relevant for understanding contemporary attitudes toward algorithmic decision-making. AI technologies often operate as opaque systems whose internal logic remains inaccessible to ordinary citizens. As a result, individuals frequently evaluate AI not on the basis of technical knowledge but through their level of trust in the institutions responsible for developing, regulating, and implementing these technologies. Recent empirical studies demonstrate that public trust in artificial intelligence is strongly associated with perceptions of transparency, accountability, fairness, and institutional competence (Robles & Mallinson, 2023). Citizens are generally more likely to support the adoption of AI when they believe that governments and regulatory authorities possess sufficient capacity to monitor technological development and protect the public interest. Conversely, low levels of institutional trust often lead to heightened concerns regarding privacy violations, surveillance, algorithmic discrimination, and the concentration of power in the hands of governments or technology corporations.

Research also suggests that public attitudes toward AI vary significantly across social groups. Factors such as age, educational attainment, digital literacy, political orientation, and previous experience with digital technologies influence both perceptions of risk and support for regulatory intervention (Zhang & Dafoe, 2019). Younger and more technologically experienced individuals tend to perceive AI as a source of innovation and economic opportunity, whereas older populations often express greater concern regarding employment displacement, social inequality, and the erosion of human autonomy. These differences indicate that public perceptions of AI cannot be reduced to simple support-or-opposition dichotomies but rather reflect broader patterns of social stratification and technological engagement. Another important strand of research examines the relationship between trust and regulatory preferences. Comparative studies demonstrate that citizens who possess high levels of trust in public institutions are generally more willing to accept state involvement in technological governance, whereas individuals with lower levels of institutional trust tend to favor market-based or decentralized regulatory approaches (Araujo et al., 2020). This finding is particularly relevant in comparative international contexts, where historical experiences with government institutions significantly shape attitudes toward digital governance and state intervention. Furthermore, scholars increasingly argue that social acceptance represents a critical precondition for the long-term legitimacy of AI governance systems. Regulatory frameworks that fail to account for public concerns may encounter resistance even when they are technically sophisticated or legally robust (Longoni et al., 2019). Consequently, understanding how citizens perceive AI-related risks and regulatory initiatives has become an essential component of effective governance. From this perspective, sociological analysis provides valuable insights into the mechanisms through which trust, legitimacy, and public participation influence the success or failure of AI regulation. Despite

the rapid growth of research on public attitudes toward artificial intelligence, existing studies remain heavily concentrated in North America, Western Europe, and East Asia. Much less attention has been devoted to emerging and developing regions, particularly Central Asia, where digital transformation is progressing rapidly but where empirical evidence regarding societal perceptions of AI remains limited. This geographical imbalance highlights the need for further research examining how trust, cultural values, and institutional contexts shape public responses to AI governance in non-Western societies.

Results and discussion

Cultural differences in the perception of AI regulation

The European continent was among the first in the world to raise the issue of legal regulation of AI technologies, foreseeing in it a threat to national security, fearing privacy violations, and discrimination based on gender, race, and religious preferences [7]. In the past year, 2025, the EU AI Act – the European Artificial Intelligence Act (EU Artificial Intelligence Act, AI Act) – became the world's first comprehensive and all-encompassing regulatory act specifically dedicated to the regulation of artificial intelligence at the regional level. Approved by the European Parliament in the spring of 2024, it entered into force in 2025 and provides for the phased implementation of requirements depending on the level of risk of AI systems.

The Regulation covers the entire lifecycle of artificial intelligence: from the design and model training stage to their commercial deployment and subsequent use. The AI Act establishes mandatory legal requirements for a wide range of entities, including:

- companies developing and placing AI systems on the EU market;
- organizations using artificial intelligence in their activities (including hiring, credit scoring, biometric identification, and other sensitive processes);
- providers integrating machine learning models into products and services accessible to European users.

Thus, the main objectives of the AI Act are as follows:

Increasing trust in AI – establishing uniform standards of transparency, safety, and accountability in the use of AI for commercial and governmental purposes.

Risk management – introducing a classification of AI by risk levels, from minimal to unacceptable, and establishing corresponding requirements for each category.

Standardization of processes – mandatory maintenance of technical documentation, registration of systems in the EU registry, and conducting audits for compliance with requirements.

Responsible technology development – stimulating innovation while simultaneously preventing human rights violations and abuses of AI in the areas of surveillance and discrimination [8].

One of the most discussed features of the EU AI Act has become its extraterritorial application. The European Regulation extends its effect far beyond the borders of the Union: it is binding not only for European companies but also for all foreign developers if their AI systems in any way affect the interests of individuals or legal entities within the EU territory. Thus, Europe has de facto established a global standard for the regulation of artificial intelligence. The law applies to large international corporations, developers of SaaS platforms, cloud services, and even small startups (something similar is observed in China, as discussed below) that offer their products to European users or work with their data. This has turned the EU into one of the main "trendsetters" in global digital policy. At the same time, European society demonstrates the highest level of prudence and criticality towards artificial intelligence technologies. According to the results of the Special Eurobarometer 554, 84 percent of EU citizens are convinced that the development of AI must be accompanied by "strict state regulation," with more than 70 percent of respondents expressing serious concern about issues of personal data protection and the risk

of discriminatory decisions [9]. It is entirely justified that the European regulatory model (EU AI Act) enjoys broad public support. It organically reflects the fundamental values of European culture – the absolute priority of human rights and freedoms, the principle of transparency, ethical responsibility, and the special protection of vulnerable groups of the population.

Pragmatism and innovative liberalism of the united states.

In the United States, public sentiment appears noticeably more positive and pragmatically business-oriented. According to a 2025 Pew Research Center study, only 49 percent of Americans support strict government control over the development of artificial intelligence. At the same time, a significant portion of the population believes that business is capable of self-regulation in this sphere. This clearly reflects the key cultural values of America: the importance of personal freedom, the spirit of entrepreneurship, and a traditionally wary attitude toward “big government” and its interference [10]. It should be noted that back during Barack Obama’s presidency in 2016, the National Science and Technology Council approved the National Strategic Plan for the Development of Artificial Intelligence [11]. It is important to emphasize that awareness and study of the ethical, legal, and social implications of implementing AI systems were identified in this document as one of the main strategies for the future development of the United States. In addition, since February 2019, the United States has had a Strategic Plan for AI Research and Development, which was updated in May 2023 by the White House Office of Science and Technology Policy [12]. The updated document reaffirmed the need to conduct research on understanding and addressing the ethical, legal, and social consequences of AI implementation. According to strategic points Nos. 3 and 4, four key R&D directions were defined:

- Investment in fundamental research to advance the core values of neural network algorithms (through the design of sociotechnical systems and consideration of the ethical, legal, and social implications of AI);
- Mitigation of social and ethical risks associated with artificial intelligence technologies;
- Use of neural networks to solve legal, ethical, and social problems;
- Forecasting risks related to the global implications of AI.

It is expected that all these directions will reduce the level of tension between the state and society – particularly among supporters of conservative views and values who demonstrate varying degrees of distrust toward the introduction of IT technologies into their daily lives.

China and the harmonious socialist society

In China, another country actively developing neural network technologies, the principle of collectivism functions effectively, accompanied by a high level of public trust in the state. This results in one of the highest levels of acceptance of government regulation of AI. According to studies conducted in 2024–2025, more than 75 percent of Chinese citizens responded positively to the active role of the state in controlling modern technologies. The development of artificial intelligence is perceived not as a threat to individual freedom, but as a tool for national development, social harmony, and strengthening the state. Collectivist culture and a high level of trust in central authority play a key role in this country. As practice in recent years has shown, AI technologies have already demonstrated their effectiveness in China’s national security system. In order to minimize crime in particularly high-risk prefectures and regions, as well as to maintain control over major technology companies (to prevent giants such as Alibaba, Baidu, and Tencent from monopolizing citizens’ personal data), the Chinese authorities have implemented the Social Credit System. This system evaluates each citizen based on specially trained parameters. The Chinese government states that the main objective of this system is not merely to ensure security, but to build a “harmonious socialist society.” The cornerstone of this social model is proclaimed to be honesty, which must be present in all actions of a citizen – from behavior on the internet to respectful treatment of one’s parents. To systematically cultivate this quality, every citizen is assigned an individual rating – points. Points are awarded for impeccable compliance with the law,

participation in socially beneficial activities, and, for example, timely repayment of credit obligations. Points are deducted for various violations depending on their severity. If the final rating falls below the established threshold, a person's life risks turning into a series of serious restrictions and prohibitions. When the first version of the system was introduced in September 2016, the Chinese authorities published a detailed list of sanctions applied to individuals with low ratings, including:

- Prohibition from employment in state institutions;
- Loss of access to social security;
- Enhanced customs inspections;
- Ban on holding managerial positions in the food and pharmaceutical industries;
- Denial of airplane tickets and sleeping berths on overnight trains;
- Ban on booking luxury hotel rooms and tables in expensive restaurants;
- Denial of admission to prestigious private schools for the children of violators.

From the perspective of the Chinese leadership, distinguishing between honest and dishonest behavior is quite simple – the dividing line runs exactly along the boundary between compliance with and violation of the law. However, many experts agree that Chinese laws regulate everyday human existence far more meticulously and intrusively than the regulatory acts of Central Asian countries [13]. These measures fully align with China's doctrine for the development of next-generation artificial intelligence, presented by the State Council in the "New Generation Artificial Intelligence Development Plan" in 2017, designed for the period 2020-2030. As Professor Alexander Arsenievich Petrov of the Moscow State Law University named after O.E. Kutafin writes in his article "Chinese Digital Profile or Social Trust Scoring System," this project includes several directions:

1. Strengthening the computing power, performance, analytical potential, and predictive capabilities of all socio-economic and military-political structures, including the SCS system.
2. Transforming China into a scientific and technological superpower.
3. Developing unique advantages in the military-technological sphere.
4. Turning China into the world's leading center for cutting-edge AI technologies that sets global trends.
5. Solving internal political tasks of large-scale control over population behavior to ensure stability and preserve the current government.

According to Petrov, the implementation of these tasks is supported by massive state funding and the financial resources of private high-tech companies. By 2030, no less than \$150 billion is allocated for the development of next-generation AI, and another \$1.5 trillion for the computerization of state institutions and programs [14]. It is expected that in the coming years (by 2030), the Chinese AI industry will occupy a very significant, if not leading, position in the world, exceeding 1 trillion yuan in core sectors and 10 trillion yuan in related industries.

AI in Central Asia: the search for its own model

The so-called "Asian Tigers" – Singapore, South Korea, and Japan – are not lagging behind the United States, Europe, and China. These countries demonstrate a balanced model of AI development, where high technological optimism is smoothly combined with support for government regulation in matters of security and ethics. The population of these countries, like the Chinese, trusts the state as an effective moderator of technological progress and already has certain advantages in this regard. Speaking about Central Asia and Kazakhstan, it can be confidently stated that Kazakhstan, as the most digitally advanced state in the region, is in a unique position. Today, Kazakhstan carefully studies, analyzes, and adapts the best international practices (the European risk-based model) to its legislative initiatives. By the Decree of the President of the Republic of Kazakhstan dated September 18, 2025, a separate ministry was established – the Ministry of Artificial Intelligence and Digital Development of Kazakhstan [15]. However, despite all

its positive aspects, the creation of a separate ministry does not guarantee instant success in the race to become a regional digital hub in Central Asia, as this is a long and systematic process with its own political and economic risks and costs. Nevertheless, in his recent Address to the Nation “Kazakhstan in the Era of Artificial Intelligence: Current Tasks and Their Solutions Through Digital Transformation,” President Kassym-Jomart Tokayev set an extremely ambitious goal – to transform Kazakhstan into a fully digital country within three years [17]. As of early 2026, the ambitious goals set by the leadership of the Republic of Kazakhstan are being systematically implemented. Two landmark laws were signed: the Law “On Artificial Intelligence” dated November 17, 2025 No. 230-VIII and the Digital Code dated January 9, 2026 No. 255-VIII. Preliminary sociological data show that Kazakhstani society demonstrates a mixed perception of AI technologies in everyday life:

- High technological optimism among young people and residents of large cities;
- Significant concern about privacy and digital control;
- Relatively high trust in the state as a regulator (higher than in Western Europe, but lower than in China) [18].

In other Central Asian countries such as Kyrgyzstan, Uzbekistan, and Tajikistan, the level of trust in state regulation of AI correlates with overall trust in government. However, there too, the adult population tends to be more conservative and less active in mastering AI technologies compared to the younger generation. As shown in Figure 1, differences in AI governance models can be interpreted as the outcome of interactions between cultural values, institutional trust, and societal perceptions of technological risks.

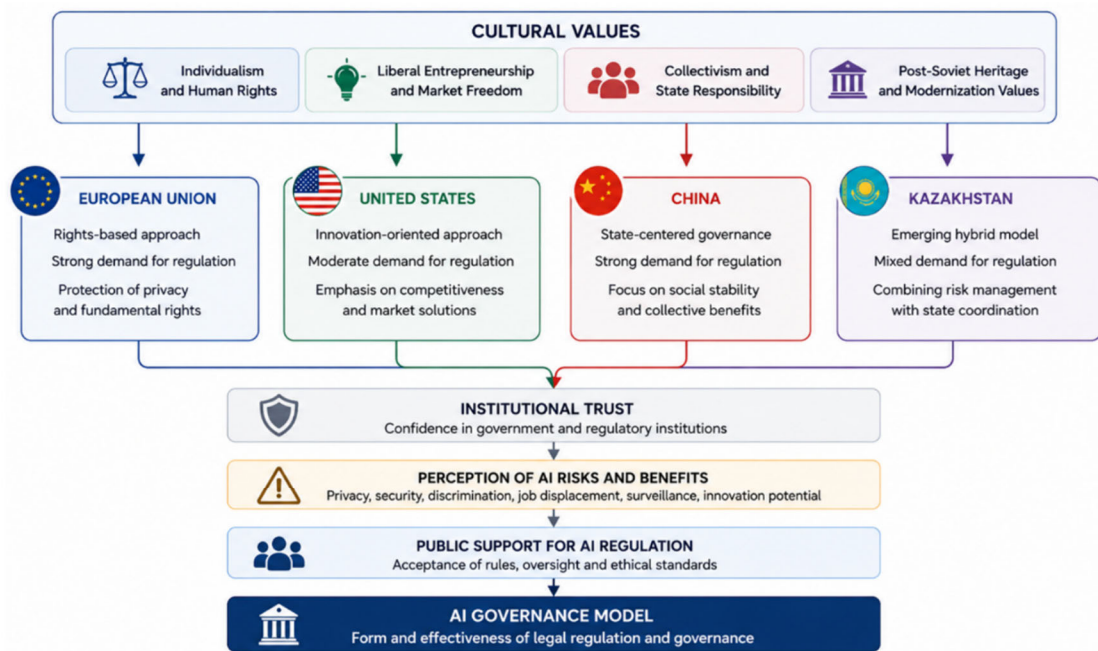


Figure 1. Sociocultural foundations of contemporary AI governance models

The European model derives its legitimacy primarily from the protection of fundamental rights and transparency mechanisms, whereas the American approach remains strongly connected to market liberalism and innovation-oriented development. By contrast, the Chinese model is characterized by a higher degree of public acceptance of state intervention, reflecting the importance of collective interests and confidence in centralized governance structures. Kazakhstan occupies a distinctive position within this spectrum. The country's emerging AI governance framework incorporates elements from multiple international models while simultaneously reflecting domestic institutional and cultural realities. This observation supports

the argument that successful AI regulation cannot be transferred mechanically from one context to another. Rather, governance frameworks must be adapted to existing patterns of institutional trust, public expectations, and societal values. Consequently, Kazakhstan's future success in AI governance will depend on its ability to balance technological innovation, regulatory oversight, and public legitimacy within a rapidly evolving digital environment.

The comparative analysis demonstrates that approaches to AI governance differ not only because of legal or technological factors but also because of broader sociocultural and institutional contexts. Consistent with the findings of Cath et al. (2018) and Jobin et al. (2019), the regulation of artificial intelligence reflects underlying societal values concerning authority, individual rights, risk management, and technological progress. The European model represents the clearest example of a rights-based approach to AI governance. Public support for the EU AI Act appears to be closely linked to the historical development of European legal culture, where the protection of privacy, transparency, and fundamental rights occupies a central position. As Veale and Borgesius (2021) argue, the European regulatory framework seeks to transform ethical principles into legally enforceable obligations. From the perspective of institutional trust theory, citizens are willing to support extensive regulation because regulatory institutions are generally perceived as legitimate guardians of public interests. The United States presents a substantially different model. Although concerns regarding algorithmic accountability and discrimination are increasingly visible, regulatory preferences remain strongly influenced by traditions of market liberalism and technological entrepreneurship. Consistent with the observations of Cath et al. (2018), American society tends to view innovation as a primary source of economic growth and global competitiveness. Consequently, regulatory interventions are often evaluated in terms of their potential impact on innovation rather than solely through considerations of risk reduction. China illustrates an alternative governance paradigm characterized by strong state involvement and comparatively high public acceptance of governmental oversight. As Roberts et al. (2021) note, Chinese AI governance is embedded within broader national development strategies that prioritize social stability, economic modernization, and national security. In this context, institutional trust operates differently from Western democracies. Public support for AI regulation is derived less from concerns about individual rights and more from expectations regarding state effectiveness and collective welfare.

Kazakhstan occupies an intermediate position between these models. The country's emerging approach to AI governance combines elements of European risk-based regulation with a stronger role for state coordination and strategic planning. This hybrid orientation reflects both the country's aspiration to integrate into global digital governance frameworks and its post-Soviet institutional legacy. The findings suggest that Kazakhstani society demonstrates neither the strong regulatory skepticism observed in some Western contexts nor the extensive acceptance of centralized technological governance characteristic of China. These results support the argument advanced by Birkstedt et al. (2023) that AI governance should be understood as a sociotechnical phenomenon rather than merely a legal framework. Regulatory effectiveness depends not only on legislative quality but also on the degree to which governance arrangements correspond to prevailing cultural values, public expectations, and patterns of institutional trust. Consequently, the long-term success of Kazakhstan's AI governance strategy is likely to depend on its ability to balance innovation, public participation, transparency, and effective state oversight. Public demand for AI regulation emerges not simply because artificial intelligence creates opportunities but because it simultaneously generates new forms of uncertainty related to privacy, accountability, surveillance, and social inequality. Different societies respond to these risks through distinct institutional mechanisms, resulting in the diversity of governance models observed across contemporary AI regimes.

Conclusion

Global experience convincingly proves that the legal regulation of AI is determined primarily by the current legislative framework, developed technological initiatives, and clear state regulation regarding the application of neural systems in citizens' public life. At the same time, it can be concluded that no country in the world currently has a universal model that works equally effectively across all social structures. Kazakhstan, followed by other Central Asian countries, is pursuing a hybrid model of AI development that combines the European risk-based approach, consideration of national cultural characteristics and high demand for state protection, mechanisms of public participation, and the improvement of digital and legal literacy of the population. As practice in recent years has shown, this approach is capable of ensuring not only technological development but also a systematic transition from a regulated and limited model of neural network implementation to their full social legitimacy within the system of legal regulation and digital security for every citizen in Central Asian countries.

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Physical and Mathematical Sciences

ТЕРБЕЛІСТЕР МЕН ТОЛҚЫНДАРДЫ ОҚЫТУДА ЦИФРЛЫҚ ТЕХНОЛОГИЯЛАРДЫ ПАЙДАЛАНУДЫҢ ПЕДАГОГИКАЛЫҚ МҮМКІНДІКТЕРІ

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Аңдатпа: Мақалада физиканың «Тербелістер мен толқындар» бөлімін оқыту барысында цифрлық білім беру платформаларын пайдаланудың педагогикалық және әдістемелік мүмкіндіктері қарастырылады. Қазіргі білім беру жүйесіндегі цифрландыру үдерісі оқытудың жаңа формалары мен технологияларын енгізуді талап етеді. Физика пәніндегі күрделі және абстрактілі ұғымдарды түсіндіруде цифрлық платформалар маңызды рөл атқарады. Зерттеу барысында PhET, GeoGebra және виртуалды зертханалар сияқты цифрлық ресурстардың оқу процесіне әсері талданды. Цифрлық платформаларды пайдалану оқушылардың танымдық белсенділігін арттырып, теориялық білімді тәжірибемен ұштастыруға мүмкіндік беретіні анықталды.

Кілт сөздер: цифрлық білім беру платформалары, тербелістер мен толқындар, физиканы оқыту, PhET симуляциялары, виртуалды зертхана, интерактивті оқыту, педагогикалық эксперимент.

Кіріспе. Қазіргі қоғамның қарқынды цифрлануы білім беру жүйесіне де жаңа талаптар қойып отыр. Білім беру сапасын арттыру, оқыту үдерісін жетілдіру және білім алушылардың танымдық белсенділігін дамыту мәселелері бүгінгі күні ерекше маңызға ие. Физика пәнінің «Тербелістер мен толқындар» бөлімін оқыту – оқушылар үшін жиі қиындық туғызатын тақырыптардың бірі. Бұл тақырып абстрактілі математикалық аппаратқа негізделгендіктен, оны тек теориялық тұрғыдан оқыту жеткіліксіз болып шығады. Осы мәселенің шешімі ретінде цифрлық білім беру платформаларын оқу үдерісіне кіріктіру мүмкіндіктері зерттеледі.

Зерттеудің мақсаты – мектептің оқу процесінде тербелістер мен толқындар тақырыбын оқытуды жетілдіру үшін цифрлық білім беру платформаларын тиімді құрал ретінде қолдану мүмкіндіктерін көрсету. Осы мақсатқа жету үшін теориялық талдау, педагогикалық эксперимент және сандық деректерді өңдеу әдістері қолданылды.

Негізгі бөлім.

Цифрлық білім беру платформалары – білім беру мазмұнын ұйымдастыруға, оқу процесін басқаруға және білім алушылардың зерттеу дағдыларын қалыптастыруға арналған электрондық жүйелер. Мектеп физикасы контексінде ең жиі қолданылатын платформалар – PhET Interactive Simulations (Колорадо университеті), GeoGebra және Algodoo болып табылады [1].

Физиканы оқытуда цифрлық платформалардың басты артықшылығы – физикалық құбылыстарды визуализациялау мүмкіндігі. Көптеген физикалық процестерді нақты жағдайда бақылау қиын немесе арнайы зертханалық құралдарды қажет етеді. Ал цифрлық

модельдеу құралдары арқылы оқушылар бұл құбылыстарды интерактивті түрде зерттей алады.

«Тербелістер мен толқындар» бөлімін оқыту барысында PhET платформасының мүмкіндіктері ерекше маңызды. «Masses and Springs», «Pendulum Lab», «Wave on a String» және «Wave Interference» симуляциялары оқушыларға тербеліс параметрлерінің өзгеруін бақылауға, толқындардың таралу заңдылықтарын зерттеуге және эксперименттік жұмыстар жүргізуге мүмкіндік береді.

Мысалы, «Wave on a String» симуляциясы арқылы оқушылар толқын ұзындығы, жиілік және толқын жылдамдығы арасындағы байланысты тәжірибелік жолмен анықтай алады. Ал «Pendulum Lab» бағдарламасы математикалық маятниктің ұзындығы мен тербеліс периоды арасындағы тәуелділікті зерттеуге жағдай жасайды.

Аталған платформалардың негізгі педагогикалық артықшылықтары:

Интерактивтілік – оқушылар виртуалды зертханаларда тербеліс және толқын процестерін модельдей отырып, параметрлерді өзгертіп, нәтижені бірден бақылайды. Зерттеулер интерактивті ортада материалды 30–40% тиімдірек меңгерілетінін дәлелдейді [2].

Визуализация – гармоникалық тербелістердің амплитудасы мен фазасы, дыбыс толқындарының таралуы сияқты күрделі физикалық құбылыстар динамикалық анимация арқылы нақты бейнеленеді.

Модельдеу мүмкіндігі – оқушы бір параметрді өзгерте отырып, барлық басқаларын тіркеп ұстайды. Мысалы, маятник ұзындығы 4 есе артқанда тербеліс периодының 2 есе артатынын ($T = 2\pi\sqrt{l/g}$) тәжірибелік жолмен «ашуға» болады [3].

Қолжетімділік – виртуалды ресурстарға интернет арқылы кез келген уақытта қол жеткізуге болады. Бұл зертхана жабдықтары жеткіліксіз мектептердің оқушыларына да заманауи тәжірибелік оқуға қатысуға мүмкіндік береді.

Тербелістер мен толқындар тақырыбын оқытудағы мәселелер

Ғылыми-педагогикалық зерттеулер «Тербелістер мен толқындар» тарауын оқытуда оқушыларда жиі кездесетін қате пайымдарды анықтаған. Wittmann (1998) жүргізген зерттеуде бірінші курстан кейін де оқушылардың 83%-ы толқынның таралу жылдамдығын дұрыс түсінбейтіні анықталды [4]. Кең таралған қателіктер:

- толқын жылдамдығы мен тасымалдаушы ортаның бөлшектер жылдамдығын шатастыру;
- амплитуда мен жиілік арасындағы тәуелділік туралы қате пайым;
- фазалық жылжу ұғымын уақытша жылжумен шатастыру;
- суперпозиция принципін дұрыс түсінбеу.

Дәстүрлі оқыту форматы – мұғалімнің түсіндірмесі мен формулаларды жаттату – бұл қате пайымдарды жою үшін жеткіліксіз. Мектеп зертханаларының жабдықталу деңгейінің жетіспеушілігі де теорияның практикамен байланысын жоятын жағдай туғызады [5].

Цифрлық платформалардың психологиялық-педагогикалық негіздері

Цифрлық білім беру платформаларының тиімділігі олардың технологиялық мүмкіндіктерімен ғана емес, психологиялық-педагогикалық теориялармен де негізделеді. Р. Майердің мультимедиалық оқыту теориясы бойынша адам ақпаратты екі арна – визуалды және вербалды арналар арқылы қабылдайды. Цифрлық платформалар мәтін, графика, анимация және дыбысты біріктіру арқылы оқу материалын тиімді меңгеруге жағдай жасайды.

Конструктивистік оқыту теориясы бойынша білім дайын күйінде берілмейді, оқушы оны өз тәжірибесі арқылы қалыптастырады. Виртуалды зертханалар мен симуляциялар білім алушыларға тәжірибе жүргізуге, болжамдар жасауға және нәтижелерді талдауға мүмкіндік береді. Бұл өз кезегінде зерттеушілік дағдылардың қалыптасуына ықпал етеді.

Сонымен қатар цифрлық платформалар өзіндік реттелетін оқуды дамытуға мүмкіндік береді. Оқушылар оқу қарқынын өздері таңдап, қажетті материалдарға қайта оралып, білім деңгейін өздігінен бағалай алады.

Цифрлық платформаларды қолданудың әдістемелік жүйесі

Зерттеу барысында тербелістер мен толқындар тақырыбын оқытуда цифрлық платформаларды 5E педагогикалық моделімен (Engage – Explore – Explain – Elaborate – Evaluate) ұштастыру жүйесі жасалды. Үлгілік сабақтың (45 минут) құрылымы:

1. Тарту кезеңі (5 мин) – мұғалім тартымды физикалық сұрақ қояды. Мысалы: «Неліктен шыны дыбыстан сынуы мүмкін?» – резонанс тақырыбына деген қызығушылық оянады.

2. Теориялық кіріспе (7 мин) – негізгі ұғымдар мен формулалар қысқаша берілуі.

3. Симуляциямен зерттеу кезеңі (15 мин) – оқушылар жұпта немесе жеке PhET симуляциясында берілген жұмыс парағы бойынша деректер жинайды, гипотезаларын тексереді.

4. Топтық талқылау (8 мин) – оқушылар нәтижелерімен бөліседі, мұғалім теориялық тұжырымды нақтылайды.

5. Қорытынды тапсырма (10 мин) – жаңа контекстте (музыкалық аспап, сейсмограф) білімді қолданатын шығармашылық тапсырма орындалады.

Тербелістер мен толқындар тақырыбының нақты кіші бөлімдері үшін арнайы симуляциялар таңдалды: еркін тербелістерге – PhET «Pendulum Lab» (маятник ұзындығы мен периодтың тәуелділігін зерттеу), резонансқа – PhET «Resonance», механикалық толқындарға – PhET «Wave on a String», дыбыс тарауына – PhET «Sound» симуляциялары.

Халықаралық тәжірибе

Әлемдік тәжірибе цифрлық платформаларды физиканы оқытуда пайдаланудың жоғары тиімділігін көрсетеді. Финляндия мектептерінде цифрлық симуляциялар зерттеу негізіндегі оқыту тәсілдерімен ұштастырылып қолданылады. Оқушылар физикалық заңдылықтарды дайын түрде қабылдамай, виртуалды тәжірибелер арқылы өздері анықтайды.

Сингапурда виртуалды зертханалар мектеп бағдарламасының міндетті компоненттерінің бірі болып табылады. Бұл елде барлық білім беру ұйымдары заманауи цифрлық ресурстармен қамтамасыз етілген.

АҚШ-та әзірленген PhET платформасы қазіргі уақытта әлемнің жүзден астам елінде қолданылады. Платформаның тиімділігі көптеген халықаралық зерттеулермен дәлелденген. Қазақстанда да «Цифрлық Қазақстан» бағдарламасы аясында білім беру процесіне цифрлық технологияларды енгізу бағытында жұмыстар жүргізілуде.

Қорытынды.

Бүгінгі таңда білім беруді цифрландыру тренді физиканы оқытудың әдістемелік жүйесін түбегейлі жаңартуды талап етеді. Осы тұрғыда интерактивті цифрлық платформалар оқу процесін көрнекілендірудің, физикалық құбылыстарды модельдеудің және теория мен практиканы байланыстырудың қуатты құралына айналды.

Зерттеу барысында мектеп физикасының ең күрделі әрі дерексіз (абстрактілі) бағыттарының бірі – «Тербелістер мен толқындар» бөлімі талданды. Бұл тақырыпты дәстүрлі тәсілмен меңгеру кезінде оқушыларда толқындық процестер мен резонанс құбылыстарына қатысты қате түсініктердің қалыптасу қаупі жоғары. Заманауи симуляциялар бұл қиындықтарды тиімді еңсеруге, күрделі процестерді визуалды қабылдауға мүмкіндік береді. Цифрлық ресурстарды 5E педагогикалық моделімен біріктіре қолдану білім алушылардың зерттеушілік дағдылары мен танымдық белсенділігін арттыратыны дәлелденді.

Дегенмен, виртуалды оқытудың табыстылығы мектептің техникалық базасына, мұғалімнің IT-құзыреттілігіне және экрандық тәжірибе мен шынайы зертханалық

жұмыстардың өзара теңгеріміне тікелей байланысты. Қорыта айтқанда, цифрлық платформаларды физика сабақтарына әдістемелік тұрғыдан дұрыс кіріктіру – білім сапасын көтерудің, оқушылардың функционалдық сауаттылығын арттырудың және заманауи жаратылыстану-ғылыми білім беруді дамытудың басты кепілі болып табылады.

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БЕЙІНДІ СЫНЫПТАРДА ТРИГОНОМЕТРИЯЛЫҚ ТЕҢДЕУЛЕРДІ ОҚЫТУДА ДЕҢГЕЙЛІК ТАПСЫРМАЛАР ЖҮЙЕСІН ҚОЛДАНУ

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Аннотация: бұл мақалада бейіндік сыныптарда тригонометриялық теңдеулерді оқытуда деңгейлік тапсырмалар жүйесін қолданудың тиімділігі қарастырылады. Тригонометриялық теңдеулерді меңгеру барысында оқушылардың кездесетін қиындықтары талданып, оларды еңсерудің әдістемелік жолдары ұсынылады. Автор тригонометриялық теңдеулерді төрт деңгейге бөліп, әр деңгейге сәйкес тапсырмалар жүйесін ұсынады. Ұсынылған тәсіл оқушылардың білім сапасын арттыруға және есеп шығару дағдыларын дамытуға бағытталған.

Кілт сөздер: бейіндік сыныптар, математиканы оқыту, тригонометриялық теңдеулер, оқыту әдістемесі, деңгейлік тапсырмалар жүйесі, дифференциация, педагогикалық эксперимент, оқу үдерісі, білім сапасы, есеп шығару дағдылары

Аннотация: В данной статье рассматривается эффективность использования системы уровневых заданий при обучении тригонометрическим уравнениям в профильных классах. Проанализированы трудности, с которыми сталкиваются учащиеся при изучении тригонометрических уравнений, и предложены методические пути их преодоления. Автор предлагает систему заданий, разделённую на четыре уровня в соответствии со степенью сложности. Предложенный подход направлен на повышение качества знаний учащихся и развитие навыков решения задач.

Ключевые слова: профильные классы, обучение математике, тригонометрические уравнения, методика обучения, система уровневых заданий, дифференциация, педагогический эксперимент, учебный процесс, качество знаний, навыки решения задач.

Abstract: This article examines the effectiveness of using a level-based task system in teaching trigonometric equations in specialized classes. The difficulties faced by students in learning trigonometric equations are analyzed, and methodological approaches to overcoming them are proposed. The author presents a system of tasks divided into four levels according to their complexity. The proposed approach is aimed at improving the quality of students' knowledge and developing their problem-solving skills.

Keywords: specialized classes, mathematics education, trigonometric equations, teaching methodology, level-based task system, differentiation, pedagogical experiment, learning process, quality of knowledge, problem-solving skills.

Кіріспе

Қазіргі білім беру жүйесінде бейіндік оқыту оқушылардың жеке қабілеттерін дамытуға және олардың болашақ кәсіби бағыттарын анықтауға мүмкіндік беретін маңызды бағыттардың бірі болып табылады. Бейіндік сыныптарда математиканы оқыту мазмұны тереңдетілген сипатқа ие болып, оқушылардан жоғары деңгейдегі білім мен дағдыларды талап етеді.

Математика курсының маңызды бөлімдерінің бірі болып табылатын тригонометриялық теңдеулер тақырыбы оқушылар үшін күрделі тақырыптардың қатарына жатады. Бұл тақырыпты меңгеру барысында оқушылар жиі тригонометриялық формулаларды қолдануда, теңдеулерді түрлендіруде және шешімнің жалпы түрін жазуда қиындықтарға тап болады.

Осыған байланысты тригонометриялық теңдеулерді оқыту үдерісін жетілдіру және оны тиімді ұйымдастыру қажеттілігі туындайды. Қазіргі педагогикалық зерттеулерде оқытуды саралау, яғни оқушылардың деңгейіне қарай тапсырмаларды ұсыну маңызды тәсілдердің бірі ретінде қарастырылады.

Сондықтан бұл мақалада тригонометриялық теңдеулерді оқытуда деңгейлік тапсырмалар жүйесін қолдану мәселесі қарастырылады.

Негізгі бөлім

1. Тригонометриялық теңдеулерді оқытудағы негізгі қиындықтар

Тригонометриялық теңдеулер мектеп математика курсына дағы күрделі тақырыптардың бірі болып табылады. Әсіресе бейіндік сыныптарда бұл бөлімді тереңдетіп оқыту оқушылардан жоғары деңгейдегі математикалық дайындықты талап етеді. Алайда тәжірибе көрсеткендей, оқушылар тригонометриялық теңдеулерді шешу барысында бірқатар жүйелі қиындықтарға тап болады.

Ең алдымен, негізгі мәселе – тригонометриялық формулаларды жеткілікті деңгейде меңгермеу. Оқушылар жиі қосынды, айырма және екі еселенген бұрыш формулаларын шатастырады немесе оларды дұрыс қолдана алмайды. Бұл теңдеулерді түрлендіруде қателіктерге әкеледі. Сонымен қатар, алгебралық түрлендіру дағдыларының жеткіліксіздігі де айқын байқалады: оқушылар ықшамдау, ортақ көбейткішке келтіру немесе алмастыру әдістерін қолдануда қиындық көреді.

Тағы бір маңызды мәселе – шешімнің жалпы түрін жазу. Көп жағдайда оқушылар тек жекелеген шешімдерді табумен шектеліп, тригонометриялық функциялардың периодтылық қасиетін ескермейді. Сонымен қатар, есепті шешудің тиімді әдісін таңдай алмау да қиындық туғызады, себебі оқушылар көбіне бір ғана тәсілді қолдануға тырысады.

Аталған қиындықтар оқушылардың логикалық ойлау және талдау дағдыларының жеткіліксіз дамуымен де байланысты. Күрделі есептерді шешу үшін бірнеше қадамды қатар орындау және аралық нәтижелерді бағалау қажет.

Бұл мәселелердің негізгі себептерінің бірі – тапсырмалардың күрделілік деңгейінің жүйелі ұйымдастырылмауы. Осыған байланысты тригонометриялық теңдеулерді оқытуда деңгейлік тапсырмалар жүйесін қолдану қажеттілігі туындайды, өйткені ол оқушылардың білімін біртіндеп қалыптастыруға мүмкіндік береді.

2. Деңгейлік тапсырмалар жүйесінің құрылымы

Тригонометриялық теңдеулерді оқытудағы жоғарыда аталған қиындықтарды ескере отырып, оқыту үдерісін тиімді ұйымдастыру үшін тапсырмаларды жүйелі түрде құрылымдау қажеттілігі туындайды. Осыған байланысты тригонометриялық теңдеулерді оқытуда деңгейлік тапсырмалар жүйесін қолдану ұсынылады.

Деңгейлік тапсырмалар жүйесі оқушылардың білімін біртіндеп қалыптастыруға бағытталған және тапсырмаларды күрделілік деңгейіне қарай кезең-кезеңімен орындауды

көздейді. Мұндай жүйе оқушылардың жеке ерекшеліктерін ескеруге, олардың танымдық белсенділігін арттыруға және оқу нәтижелерін жақсартуға мүмкіндік береді.

Ұсынылып отырған тапсырмалар жүйесі төрт деңгейден тұрады және әр деңгей белгілі бір оқу мақсатына бағытталған.

I деңгей (базалық деңгей)

Бұл деңгейде қарапайым тригонометриялық теңдеулер қарастырылады. Тапсырмалар тригонометриялық функциялардың негізгі қасиеттерін және қарапайым формулаларды қолдануға негізделген.

Бұл деңгейдің негізгі мақсаты – оқушылардың базалық білімін қалыптастыру және негізгі формулаларды дұрыс қолдану дағдыларын дамыту.

Мысалы:

$$\sin x=0, \cos x=1$$

II деңгей (орташа деңгей)

Бұл деңгейде теңдеулерді шешу үшін түрлендіру әрекеттері қажет болады. Оқушылар қарапайым алгебралық амалдарды қолдана отырып, теңдеуді стандартты түрге келтіреді.

Бұл деңгейдің мақсаты – оқушылардың теңдеулерді түрлендіру дағдыларын дамыту және бірнеше қадамнан тұратын есептерді шешуге үйрету.

Мысалы:

$$2\sin x-1=0$$

III деңгей (күрделі деңгей)

Бұл деңгейдегі тапсырмалар бірнеше әдісті қолдануды талап етеді. Оқушылар тригонометриялық тождестволарды пайдаланып, теңдеуді ықшамдайды және оны шешудің тиімді жолын анықтайды.

Бұл деңгейдің мақсаты – логикалық ойлау қабілетін дамыту және әртүрлі әдістерді қолдану дағдыларын қалыптастыру.

Мысалы:

$$\sin^2 x - \cos x = 0$$

IV деңгей (жоғары деңгей)

Бұл деңгейде күрделі құрылымды немесе параметрі бар теңдеулер қарастырылады. Мұндай тапсырмалар оқушылардың аналитикалық ойлау қабілетін дамытып, зерттеушілік дағдыларын қалыптастырады.

Бұл деңгейдің мақсаты – оқушыларды күрделі есептерді шешуге, әртүрлі тәсілдерді салыстыруға және тиімді шешім қабылдауға үйрету.

Мысалы:

$$\sin x + \cos x = a$$

Деңгейлік тапсырмалар жүйесінің басты ерекшелігі – тапсырмалардың бірізділігі мен жүйелілігінде. Әрбір келесі деңгей алдыңғы деңгейде қалыптасқан білім мен дағдыларға негізделеді. Бұл оқушыларға оқу материалын біртіндеп меңгеруге және күрделі есептерді шешуге дайын болуға мүмкіндік береді.

Сонымен қатар, бұл жүйе оқушылардың жеке оқу қарқынын ескеруге жағдай жасайды. Әр оқушы өз деңгейіне сәйкес тапсырмаларды орындау арқылы білімін жетілдіреді, ал жоғары деңгейдегі тапсырмалар қабілеті жоғары оқушылар үшін қосымша мүмкіндік береді.

Осылайша, деңгейлік тапсырмалар жүйесі тригонометриялық теңдеулерді оқытуда тиімді әдістемелік құрал болып табылады және оқушылардың білім сапасын арттыруға ықпал етеді.

3. Деңгейлік тапсырмалар жүйесінің тиімділігі

Ұсынылған деңгейлік тапсырмалар жүйесінің тиімділігін анықтау мақсатында педагогикалық эксперимент жүргізілді. Зерттеу барысында бейіндік сынып оқушыларының тригонометриялық теңдеулерді меңгеру деңгейі талданып, оқыту үдерісінде деңгейлік тапсырмаларды қолдану нәтижелері бағаланды.

Эксперимент бірнеше кезеңнен тұрды. Алғашқы кезеңде диагностикалық бақылау жұмысы жүргізіліп, оқушылардың бастапқы білім деңгейі анықталды. Нәтижелер оқушылардың көпшілігі тригонометриялық теңдеулерді шешуде қиындықтарға тап болатынын көрсетті. Әсіресе формулаларды қолдану, теңдеулерді түрлендіру және шешімнің жалпы түрін жазуда қателіктер жиі байқалды.

Келесі кезеңде оқу үдерісіне деңгейлік тапсырмалар жүйесі енгізілді. Тапсырмалар күрделілік деңгейіне қарай біртіндеп ұсынылып, оқушылардың білімін жүйелі дамытуға бағытталды. Әр деңгей белгілі бір дағдыны қалыптастыруды көздеді: бастапқыда негізгі формулаларды меңгеру, кейін теңдеулерді түрлендіру және күрделі есептерді шешу.

Қорытынды кезеңде жүргізілген бақылау жұмысы оқушылардың білім деңгейінің артқанын көрсетті. Оқушылар есептерді сенімді шығарып, қателіктер саны азайды, логикалық ойлау қабілеті мен жұмыс қарқыны жақсарды.

Осылайша, деңгейлік тапсырмалар жүйесі тригонометриялық теңдеулерді оқытуда тиімді әдіс екені дәлелденді.

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ABOUT ARTIFICIAL INTELLIGENCE SYSTEMS

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Abstrakt

Artificial intelligence refers to computer systems that are capable of performing tasks traditionally associated with human intelligence—for example, making predictions, identifying objects, interpreting speech, and generating natural language. AI systems learn by processing large amounts of data and looking for patterns to model their own decisions. In many cases, humans will supervise the AI's learning process, reinforcing good decisions and preventing bad ones, but some AI systems are designed to learn unsupervised .

Artificial intelligence (AI) is a technology that allows machines to simulate human intelligence and cognitive capabilities. AI can be used to make decisions, solve problems, and perform tasks that are typically performed by humans.

While AI is an interdisciplinary science with many approaches, advances in machine learning, and especially deep learning, are transforming almost every industry, and AI is becoming an increasingly integral part of everyday life.

Artificial intelligence is a field of science concerned with creating computers and machines that can think, learn, and act in ways that would normally require human intelligence or that deal with data that is larger than humans can analyze.

Artificial intelligence is a technology that is currently being applied in various fields that are developing very rapidly.

Keywords: intelligence, algorithm, simulation, virtual assistants, mathematical models.

INTRODUCTION

Over time, AI systems improve their performance at specific tasks, allowing them to adapt to new inputs and make decisions without being explicitly programmed. In essence, AI teaches machines to think and learn like humans, with the goal of automating work and solving problems more efficiently [AP N2024. May 20, 2025ews. April 4].

Artificial intelligence aims to provide machines with processing and analysis capabilities similar to humans, thereby making AI a useful companion to humans in their daily lives. AI can interpret and sort through data at scale, solve complex problems, and automate multiple tasks simultaneously, saving time and filling in operational gaps left by humans.

At the operational level, AI for business use is a set of technologies based mainly on machine learning and deep learning, used for data analytics, predictions and forecasting, object classification, natural language processing, recommendations, intelligent data search, etc.

Artificial intelligence is a broad field that encompasses many different disciplines, including computer science, data analytics and statistics, hardware and software engineering, linguistics, neuroscience, and even philosophy and psychology.

AI is the foundation for machine learning and is used in almost every industry—from healthcare and finance to manufacturing and education—to help make data-driven decisions and perform repetitive or computationally intensive tasks [Brennan Whitfield. 2025].

Many existing technologies use AI to enhance capabilities. We see it in smartphones with AI assistants, trading platforms with recommendation systems, and vehicles with autonomous driving capabilities. AI also helps protect people by testing online fraud detection systems and robots for dangerous tasks, as well as leading research in health and climate initiatives.

Materials and methods

AI systems work using algorithms and data. First, large amounts of data are collected and fed into mathematical models, or algorithms, that use the data to recognize patterns and make predictions, in a process known as training. Once the algorithms are trained, they are deployed in various applications, where they continually learn from and adapt to new data. This allows artificial intelligence systems to perform complex tasks such as image recognition, language processing, and data analysis with greater accuracy and precision over time.

While the specifics vary among different AI techniques, the basic principle revolves around data. AI systems learn and improve by being exposed to large amounts of data, identifying patterns and relationships that humans might miss [Bhaskar S. 2024.].

This learning process often involves algorithms, which are sets of rules or instructions that guide the AI's analysis and decision-making. In machine learning, a popular subset of AI, algorithms are trained on labeled or unlabeled data to make predictions or classify data.

Deep learning, a further specialization, uses multilayered artificial neural networks to process data, mimicking the structure and function of the human brain. Through continuous learning and adaptation, AI systems are becoming increasingly adept at performing specific tasks, from image recognition to language translation and beyond.

Artificial intelligence (AI) is a technology that enables computers and machines to simulate human learning, comprehension, problem-solving, decision-making, creativity, and autonomy [Deiss, R., Henneberry R.2020].

Programs and devices equipped with AI can see and identify objects. They can understand and respond to human language. They can learn from new information and experience. They can provide detailed recommendations to users and experts. They can act independently, replacing the need for human intelligence or intervention.

However, in 2024, most AI researchers, practitioners, and AI-related headlines are focused on advances in generative AI (gen AI), a technology that can generate original text, images, video, and other content.

Artificial intelligence is at the heart of innovations in modern computing that unlock value for individuals and businesses. For example, optical character recognition (OCR) uses artificial intelligence to extract text and data from images and documents, transforming unstructured content into business-ready structured data and uncovering valuable insights [Russell & Norvig (2021)].

When businesses talk about AI, they often talk about “training data.” But what does that mean? Remember that AI with limited memory is AI that improves over time by being trained on new data. Machine learning is a subset of AI that uses algorithms to train data to produce results. In broad strokes, three types of learning models are often used in machine learning: Supervised learning is a machine learning model that uses labeled training data (structured data) to match a given input to an output.

Unsupervised learning is a machine learning model that learns patterns based on unlabeled data (unstructured data). Unlike supervised learning, the final result is not known ahead of time. Instead, the algorithm learns by dividing the data into groups based on attributes.

In addition to supervised and unsupervised learning, a mixed approach called semi-supervised learning is often used, in which only some of the data is labeled. In semi-supervised learning, the final result is known, but the algorithm must determine how to organize and structure the data to achieve the desired results [Kaplan, Andreas; Haenlein, Michael (2019).].

Artificial intelligence (AI) is the ability of computing systems to perform tasks typically associated with human intelligence, such as learning, reasoning, problem-solving, perception, and decision-making. It is a field of research in computer science that develops and studies methods and software that enable machines to understand their environment and use learning and

intelligence to take actions that maximize their chances of achieving specified goals. There is debate about whether artificial intelligence exhibits true intelligence or merely imitates human-like behavior by mimicking it.

High-profile applications of artificial intelligence include advanced web search engines (e.g., Google Search); recommendation systems (used by YouTube, Amazon, and Netflix); virtual assistants (e.g., Google Assistant, Siri, and Alexa); autonomous vehicles (e.g., Waymo); generative and creative tools (e.g., language models and AI art); and analysis in superhuman games and strategy games (e.g., chess) [Kate Gibson.2024].

The various subfields of artificial intelligence research are focused on specific goals and the use of specific tools. Traditional goals of artificial intelligence research include learning, reasoning, knowledge representation, planning, natural language processing, perception, and support for robotics. To achieve these goals, AI researchers have adapted and integrated a wide range of techniques, including search and mathematical optimization, formal logic, artificial neural networks, and methods based on statistics, operations research, and economics. AI also draws on psychology, linguistics, philosophy, neuroscience, and other fields.

Early researchers developed algorithms that mimicked the step-by-step thinking that humans use when solving puzzles or making logical deductions. In the late 1980s and 1990s, methods were developed for dealing with uncertain or incomplete data, using concepts from probability and economics.

Many of these algorithms are not sufficient for solving large-scale reasoning problems because they experience a "combinatorial explosion": They slow down exponentially as problems get bigger. Even humans rarely use the step-by-step deduction that early AI research could model. They solve most of their problems using fast, intuitive judgments. Accurate and efficient reasoning is an unsolved problem.[Russell &Norvig.2021]

Knowledge representation and knowledge engineering enable AI programs to intelligently answer questions and make inferences about real-world facts. Formal knowledge representations are used in content-based indexing and retrieval, scene interpretation, clinical decision support, knowledge discovery, and other areas.

Among the most difficult problems in knowledge representation are the breadth of common sense knowledge and the sub-symbolic form of the most general meaningful knowledge .

Affective computing is a field of systems that recognize, interpret, process, or simulate human feelings, emotions, and moods. For example, some virtual assistants are programmed to speak in a conversational manner or even joke around; making them more sensitive to the emotional dynamics of human interaction or facilitating human-computer interaction.

However, this tends to give naive users an unrealistic concept of the intelligence of existing computer agents. Moderate achievements in affective computing include text sentiment analysis and, more recently, multimodal sentiment analysis, in which AI classifies the emotions displayed by a videotaped subject.

Artificial intelligence (AI) is a field of computer science that aims to create machines capable of performing tasks that typically require human intelligence. Artificial intelligence allows machines to simulate human abilities such as learning, problem-solving, decision-making, and understanding. Common applications of AI include speech recognition, image recognition, content generation, recommender systems, self-driving cars, and AI agents .

CONCLUSION

The future of artificial intelligence holds great promise, with the potential to revolutionize industries, enhance human capabilities, and solve complex problems. It could be used to develop new medicines, optimize global supply chains, and power advanced robots—transforming the way we live and work.

Looking ahead, one of the next big steps for artificial intelligence is to move beyond weak or narrow AI and achieve artificial general intelligence (AGI) and eventually superintelligence. With AGI, machines will be able to think, learn, and act in the same way as humans, blurring the lines between organic and machine intelligence. This could pave the way for increased automation and problem-solving capabilities in areas such as medicine, manufacturing, transportation, and more [Toews (2023) .Van Esch, P.; Stewart Black,2021].

On the promise of technology In 2024, Anthropic CEO Dario Amodei speculates that strong AI could accelerate innovation in the biological sciences tenfold by enabling more experiments to be conducted at any given time and shortening the time between new discoveries and subsequent research.

On the other hand, the increasing sophistication of AI also raises concerns about increasing job losses, widespread misinformation, and loss of privacy. Questions remain about the potential for AI to surpass human understanding and intelligence—a phenomenon known as technological singularity, which could lead to unforeseen risks and possible moral dilemmas.

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SÜNİ İNTELLEKT SİSTEMLƏRİ

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Xülasə

Süni intellekt (AI) maşınlara insan zəkasını və idrak imkanlarını simulyasiya etməyə imkan verən texnologiyadır. Süni intellekt qərarlar qəbul etmək, proqramları həll etmək və adətən insanların yerinə yetirdiyi tapşırıqları icra etmək üçün istifadə edilə bilər.

Süni intellekt çoxsaylı yanaşmalara malik fənlərə elm olsa da, maşın öyrənməsi və xüsusilə dərin öyrənmə sahəsində irəliləyişlər demək olar ki, hər bir sənayeni dəyişir və süni intellekt gündəlik həyatın getdikcə ayrılmaz hissəsinə çevrilir. Süni intellekt, normal olaraq insan zəkasını tələb edəcək şəkildə düşünə, öyrənə və hərəkət edə bilən və ya miqyası insanların təhlil edə biləcəyindən çox olan məlumatları ehtiva edən kompüter və maşınların yaradılması ilə əlaqəli bir elm sahəsidir.

Süni intellekt kompüter elmləri, verilənlər analitikası və statistikası, aparat və proqram mühəndisliyi, dilçilik, nevrologiya, hətta fəlsəfə və psixologiya da daxil olmaqla bir çox müxtəlif fənləri əhatə edən geniş bir sahədir.

Biznes istifadəsi üçün əməliyyat səviyyəsində AI, əsasən maşın öyrənməsinə və dərin öyrənməyə əsaslanan, məlumatların analitikası, proqnozlar və proqnozlaşdırma, obyektlərin təsnifatı, təbii dil emalı, tövsiyələr, məlumatların intellektual axtarışı və s. üçün istifadə edilən texnologiyalar toplusudur.

Süni intellekt hazırda çox sürətlə inkişaf edən müxtəlif sahələrdə tətbiq olunan bir texnologiyadır.

Açar sözlər: *intellekt, alqoritm, simulyasiya, virtual köməkçilər, riyazi modellər*

Medical Sciences

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DIGITAL TRANSFORMATION AND DASHBOARD ANALYTICS IN CRISIS MANAGEMENT OF A HEALTHCARE ORGANIZATION: EVIDENCE FROM CLINIC MIRAS

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Abstract

The increasing complexity of healthcare systems, workforce shortages, financial constraints, and growing patient expectations require healthcare organizations to transition from reactive crisis response to predictive and data-driven management. This study aims to assess the role of digital transformation and dashboard analytics in strengthening organizational resilience using the case of Clinic Miras, a multidisciplinary healthcare organization in Kazakhstan. A mixed-method case study approach was applied, integrating operational, financial, workforce, and patient-related indicators. The study demonstrates that dashboard analytics enables early detection of operational bottlenecks, supports managerial decision-making, improves resource allocation, and enhances organizational resilience. Based on the findings, the MIRAS-RESILIENCE 7D framework is proposed as an integrated crisis management model for healthcare organizations.

Keywords: digital transformation, dashboard analytics, healthcare management, organizational resilience, crisis management, healthcare KPI, business intelligence.

1. Introduction

Healthcare organizations worldwide are currently operating in an increasingly complex and uncertain environment characterized by demographic shifts, epidemiological transitions, workforce shortages, financial constraints, rapid technological development, and growing patient

expectations. These challenges have significantly increased the vulnerability of healthcare organizations to operational, financial, organizational, and reputational risks. As a result, the concept of organizational resilience has become one of the central topics in contemporary healthcare management research [1,3,5,25].

According to the World Health Organization (WHO), resilient healthcare organizations are capable of anticipating, absorbing, adapting to, and recovering from disruptions while maintaining continuity of healthcare services and ensuring patient safety [1,5]. The COVID-19 pandemic further demonstrated that traditional reactive management approaches are insufficient for ensuring long-term sustainability. Healthcare organizations increasingly require predictive management systems capable of identifying weak signals and emerging risks before they evolve into full-scale organizational crises [3,5].

In recent years, digital transformation has emerged as one of the most influential drivers of organizational resilience in healthcare [2,15,17,22]. Digital technologies have transformed not only clinical practice but also management processes, decision-making mechanisms, patient communication, and performance monitoring systems. Electronic medical records, business intelligence platforms, customer relationship management systems, telemedicine services, and advanced analytics tools have become essential components of modern healthcare organizations. These technologies generate large volumes of data that can be utilized to support strategic and operational decision-making [15,17,18,23].

One of the most promising developments within digital healthcare management is the implementation of dashboard analytics [18,19]. Dashboard systems integrate data from multiple sources and provide healthcare managers with real-time information regarding key performance indicators (KPIs), patient flow, workforce capacity, financial performance, quality indicators, and patient experience measures. Unlike traditional retrospective reporting systems, dashboard analytics enables continuous monitoring of organizational performance and facilitates early detection of operational bottlenecks, service disruptions, and crisis-related risks.

The growing importance of dashboard analytics is closely associated with the development of predictive analytics in healthcare management. Contemporary healthcare organizations increasingly seek to move beyond descriptive reporting toward predictive and preventive management approaches. By combining operational, financial, workforce, and patient-related indicators within a unified analytical environment, dashboard systems provide managers with the ability to anticipate organizational challenges, optimize resource allocation, and improve responsiveness to rapidly changing conditions.

International organizations, including the World Health Organization (WHO), the Organisation for Economic Co-operation and Development (OECD), and the European Observatory on Health Systems and Policies, emphasize the importance of data-driven governance and digital maturity as critical determinants of healthcare system resilience [1,2,3,4,5]. At the organizational level, however, practical frameworks that integrate dashboard analytics into crisis management processes remain relatively underdeveloped, particularly in emerging healthcare systems.

This challenge is particularly relevant for healthcare organizations in the Republic of Kazakhstan. The healthcare sector is undergoing significant transformation associated with digitalization, expansion of primary healthcare services, increasing competition among healthcare providers, and growing expectations regarding accessibility and quality of care [2,4,15]. Under these circumstances, healthcare organizations require integrated management models capable of combining operational, financial, workforce, quality, and patient-centered indicators into a unified decision-support system.

Clinic Miras represents an illustrative example of a multidisciplinary healthcare organization operating in a dynamic and highly competitive environment. The clinic serves a rapidly growing attached population, implements digital healthcare solutions, and faces

challenges related to increasing service demand, workforce management, patient satisfaction, and operational efficiency. These characteristics make Clinic Miras an appropriate case for examining the role of digital transformation and dashboard analytics in strengthening organizational resilience.

Despite the growing body of literature on digital health, business intelligence, and healthcare analytics, limited research has examined dashboard analytics as an integrated element of crisis management at the level of individual healthcare organizations [15,18,19,22]. Existing studies predominantly focus on technological implementation, while insufficient attention has been devoted to the strategic role of dashboard systems in enhancing organizational resilience and supporting crisis preparedness.

The scientific novelty of this study lies in the development and application of the Digital Contour of the MIRAS-RESILIENCE 7D framework, which integrates dashboard analytics, KPI monitoring, predictive management, and organizational resilience principles into a unified crisis management model for healthcare organizations. Unlike existing approaches, the proposed framework combines operational, financial, workforce, quality, patient trust, and digital indicators within a comprehensive early-warning system designed to support evidence-based managerial decision-making.

The purpose of this study is to evaluate the contribution of digital transformation and dashboard analytics to crisis management and organizational resilience using the case of Clinic Miras and to develop practical recommendations for the implementation of integrated dashboard-based management systems in healthcare organizations.

2. Research Objective

The objective of this study is to evaluate the role of digital transformation and dashboard analytics in strengthening organizational resilience and crisis management capabilities of healthcare organizations using the case of Clinic Miras, as well as to develop and substantiate the Digital Contour of the MIRAS-RESILIENCE 7D framework as an integrated dashboard-based management model for early identification of crisis signals, continuous monitoring of key performance indicators, and evidence-based managerial decision-making.

To achieve this objective, the study focuses on assessing the impact of digital technologies, business intelligence tools, and dashboard analytics on operational efficiency, workforce management, patient-centered performance indicators, and organizational sustainability within a multidisciplinary healthcare organization.

To achieve the study objective, the following research objectives were established:

- ✓ To analyze current approaches to digital transformation and dashboard analytics in healthcare management.
- ✓ To assess the level of digitalization and implementation of digital management tools in Clinic Miras.
- ✓ To evaluate the effectiveness of dashboard-based monitoring of operational, workforce, quality, and patient-related indicators.
- ✓ To identify the contribution of dashboard analytics to early detection of operational and organizational risks.
- ✓ To develop the Digital Contour of the MIRAS-RESILIENCE 7D framework as an integrated crisis management mechanism for healthcare organizations.

- ✓ To formulate practical recommendations for the implementation of dashboard analytics as a tool for enhancing organizational resilience and crisis preparedness in healthcare organizations.

3. Scientific Novelty

The scientific novelty of this study lies in the development and empirical substantiation of the Digital Contour within the author's MIRAS-RESILIENCE 7D framework, designed to enhance crisis management and organizational resilience in healthcare organizations through the integration of dashboard analytics, key performance indicator (KPI) monitoring, and data-driven decision-making.

Unlike existing approaches to healthcare digitalization, which primarily focus on technological implementation and process automation, the proposed framework conceptualizes dashboard analytics as a strategic crisis management instrument capable of supporting the early identification of operational, workforce, financial, quality, and patient-related risks [2,15,22].

The study contributes to the literature by proposing an integrated Digital Dashboard Analytics Framework that combines data from medical information systems, customer relationship management platforms, operational databases, and quality management systems into a unified managerial environment for continuous monitoring and predictive assessment of organizational performance [18,19].

A further scientific contribution is the adaptation of dashboard-based management principles to the context of healthcare organizational resilience. The proposed approach enables the transformation of fragmented operational indicators into an integrated early-warning system that supports timely managerial interventions and strengthens organizational sustainability under conditions of uncertainty [20,21,25].

Using the case of Clinic Miras, the study demonstrates the practical applicability of the Digital Contour of MIRAS-RESILIENCE 7D and provides empirical evidence regarding the role of digital transformation in improving crisis preparedness, operational efficiency, and strategic responsiveness of healthcare organizations.

The originality of the proposed model lies in the integration of digital, operational, workforce, quality, financial, and patient trust indicators into a single dashboard-based crisis management architecture, which has not been previously described in the context of healthcare organizations in Kazakhstan.

Research Contribution

- **Theoretical contribution** – advancement of the concept of organizational resilience in healthcare organizations.
- **Methodological contribution** – development of the Digital Dashboard Analytics Framework.
- **Practical contribution** – validation and implementation of the MIRAS-RESILIENCE 7D model using the case of Clinic Miras.

4. Materials and Methods

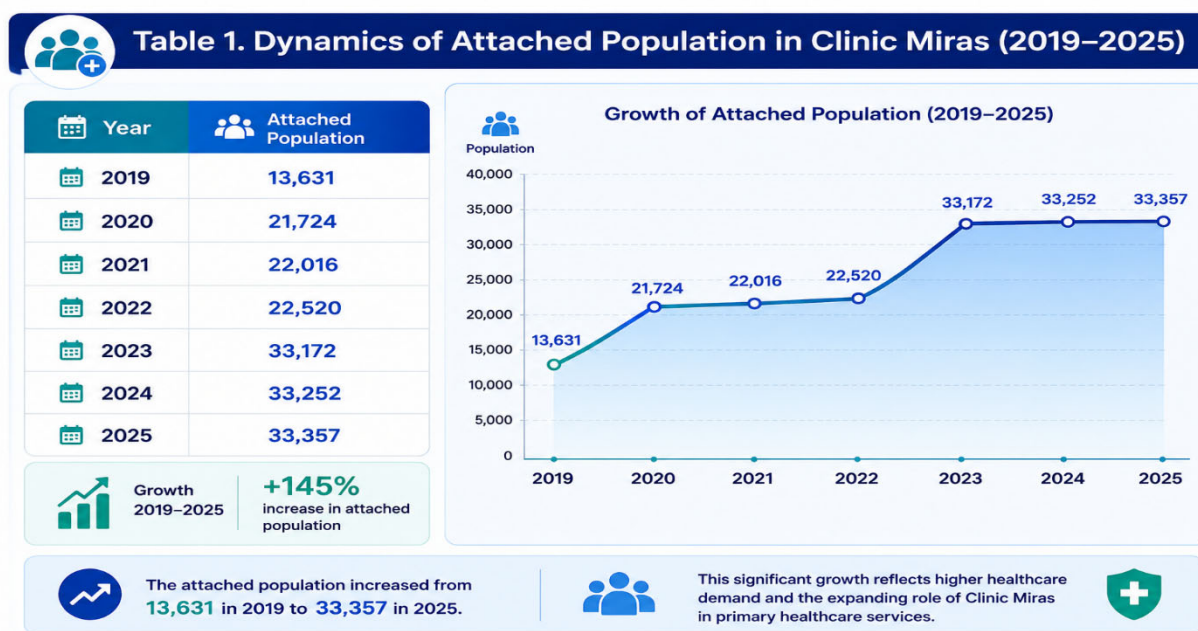
This study employed a mixed-method case study design to investigate the role of digital transformation and dashboard analytics in crisis management and organizational resilience within

a healthcare organization. The case study approach was selected because it enables an in-depth examination of complex managerial processes in a real-world organizational environment and facilitates the integration of quantitative and qualitative evidence [24,25].

The empirical basis of the study was formed using operational, organizational, workforce, quality, and patient-related data obtained from Clinic Miras, a multidisciplinary outpatient healthcare organization operating in the Republic of Kazakhstan. The observation period covered seven years, from 2019 to 2025, allowing the assessment of long-term trends in organizational development, digital transformation, and performance management.

The study utilized multiple data sources, including annual organizational reports, primary healthcare performance reports, workforce management records, patient feedback databases, complaint monitoring systems, operational statistics, digital communication platforms, and internal management dashboards. The use of multiple data sources ensured triangulation of evidence and improved the validity of the findings.

One of the key indicators analyzed in the study was the dynamics of the attached population. The number of registered patients increased from 13,631 individuals in 2019 to 33,357 individuals in 2025, representing a growth of approximately 145%. This substantial increase in service demand created additional operational pressure on healthcare resources and highlighted the importance of implementing digital management tools capable of supporting real-time monitoring and evidence-based decision-making.



To visualize the growth trend of healthcare demand, the following figure may be included in the Results section:

The study also examined patient complaints as indicators of operational and service-related risks. During 2024, Clinic Miras received 374 patient appeals and complaints. The complaint database was analyzed to identify recurring operational bottlenecks, service accessibility challenges, communication issues, and quality-related concerns. Complaint categories were subsequently incorporated into the dashboard monitoring system as early-warning indicators of organizational vulnerability.

Workforce indicators constituted another important dimension of the study. The analysis included staffing completeness, workforce turnover, qualification levels, and workforce stability. According to organizational reports, overall staffing completeness reached 95%, physician staffing completeness was 97%, and nursing staffing completeness was 94%. At the same time, workforce

turnover reached 38%, indicating the need for continuous workforce monitoring and resilience-oriented human resource management.

Digital transformation indicators were evaluated through the assessment of implemented digital initiatives, including electronic medical information systems, CRM-supported patient communication, digital appointment scheduling, IP telephony, call-center integration, paperless workflow solutions, and telemedicine-related services. Particular attention was paid to the extent to which digital technologies supported managerial decision-making and crisis preparedness.

The analysis of primary healthcare (PHC) performance indicators included service accessibility, patient routing, hospitalization pathways, referral management, and quality-related metrics. These indicators were integrated into a dashboard-based monitoring environment to support continuous performance assessment.

To evaluate organizational resilience from a managerial perspective, the study applied a dashboard analytics approach. Dashboard indicators were grouped into six major analytical domains: operational performance, workforce management, quality and patient safety, patient trust, digital transformation, and financial sustainability. The dashboard framework served as the analytical foundation of the Digital Contour within the MIRAS-RESILIENCE 7D model [6,7,18].

Table 2 Dashboard KPI Domains Used in the Study

Dashboard Domain	Key Indicators
Operational	Patient flow, waiting time, appointment accessibility
Workforce	Staffing completeness, turnover, qualification level
Quality	Complaints, service quality indicators
Patient Trust	NPS, CSI, repeat visits, patient feedback
Digital	CRM utilization, telemedicine use, digital communication
Financial	Revenue stability, operational efficiency indicators
Source: Author's compilation	

The collected data were analyzed using descriptive statistical methods, comparative trend analysis, KPI monitoring techniques, and dashboard-based performance assessment. The analytical framework was designed to identify relationships between digital transformation, operational performance, and organizational resilience, as well as to evaluate the practical applicability of dashboard analytics as a crisis management tool in healthcare organizations.

The methodological approach adopted in this study enabled the development and empirical substantiation of the Digital Contour of the MIRAS-RESILIENCE 7D framework, which integrates dashboard analytics into a comprehensive organizational resilience and crisis management system.

5. Results and Discussion

Digital Maturity of Clinic Miras

Digital transformation has become one of the key determinants of organizational resilience in modern healthcare organizations [2,15,17,25]. The assessment of Clinic Miras demonstrated a progressive transition from traditional administrative management toward data-driven and digitally supported decision-making.

The organization has implemented a number of digital initiatives, including a medical information system, CRM-supported communication channels, IP telephony, call-center integration, digital appointment scheduling, electronic documentation management, and

telemedicine-related services. These initiatives have created the foundation for continuous monitoring of operational performance and organizational resilience [15,17,22,23].

Table 3 Key Components of Digital Transformation in Clinic Miras

Digital Domain	Implemented Solution
Patient Communication	CRM system, call-center integration
Appointment Management	Digital scheduling system
Medical Records	Electronic medical information system
Internal Communication	IP telephony
Documentation	Paperless workflow
Service Accessibility	Telemedicine and remote consultations
Performance Monitoring	KPI dashboard analytics
Source: Author's compilation	

As shown in Table 3, digital transformation in Clinic Miras encompasses all major management domains, including patient communication, appointment management, medical records, documentation, and performance monitoring. The implementation of digital solutions has significantly expanded the organization's ability to monitor operational processes and support evidence-based decision-making.

Analysis of Digital Transformation

The growth of healthcare demand has significantly increased the complexity of organizational management. During the study period, the attached population increased from 13,631 individuals in 2019 to 33,357 individuals in 2025 (figure 1).

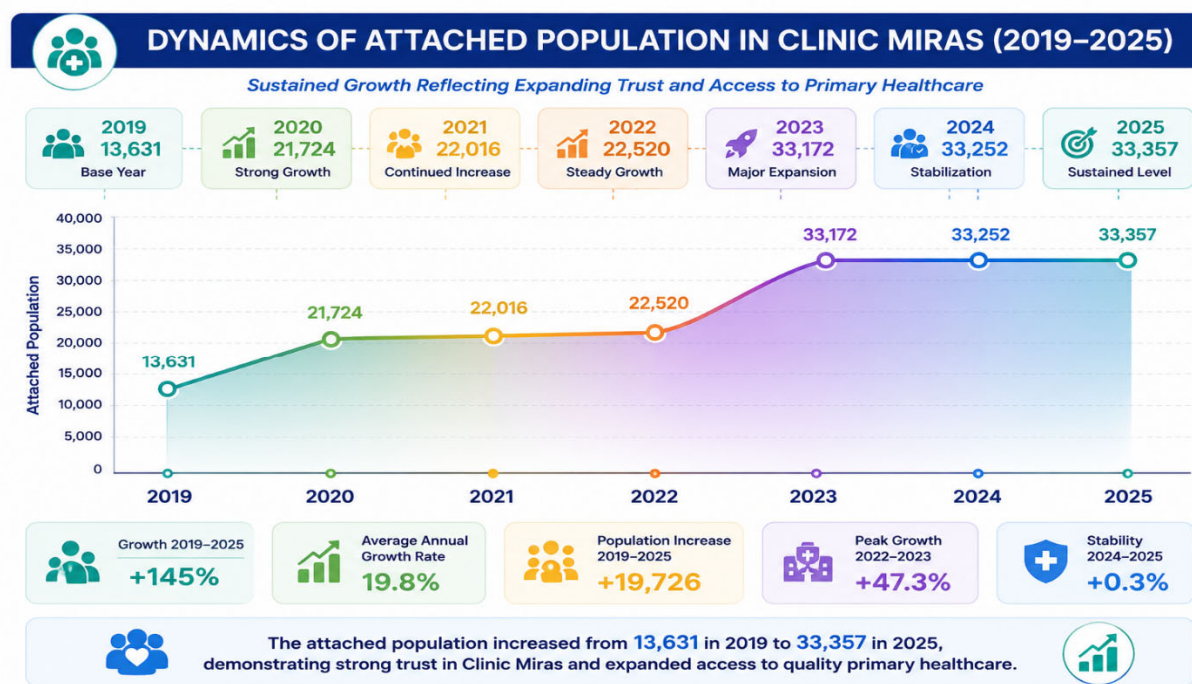


Figure 1 - Dynamics of Attached Population in Clinic Miras

Source: Author's compilation

Figure 1 demonstrates a substantial increase in the number of attached patients over the observation period. The attached population grew by approximately 145% between 2019 and 2025. Such rapid growth created additional operational pressure on healthcare resources and reinforced the necessity of implementing digital management tools capable of supporting scalable and efficient healthcare delivery.

KPI Dashboard Monitoring

One of the major outcomes of digital transformation is the establishment of a dashboard-based management system. Dashboard analytics enables healthcare managers to monitor organizational performance in real time and identify operational risks before they evolve into systemic problems [6,7,18,19].

Table 4 Dashboard KPI Structure Used in Clinic Miras

Dashboard Domain	Key Indicators
Operational Performance	Patient flow, waiting time, appointment accessibility
Workforce Management	Staffing completeness, turnover rate
Service Quality	Complaints, quality indicators
Patient Trust	NPS, CSI, repeat visits
Financial Sustainability	Revenue and operational efficiency
Digital Performance	CRM utilization, telemedicine indicators
Source: Author's compilation	

Table 4 illustrates the integrated dashboard architecture developed for Clinic Miras. Unlike traditional reporting systems, dashboard monitoring combines operational, workforce, quality, patient-related, and financial indicators within a single analytical environment, facilitating rapid managerial response to emerging risks.

Patient Flow Analysis

Patient flow management is one of the most important elements of operational resilience in healthcare organizations. The increasing number of attached patients has led to higher demand for consultations, diagnostic services, and preventive healthcare programs.

The analysis revealed several operational challenges:

- uneven patient flow distribution;
- appointment accessibility limitations;
- overload of specific specialists;
- increased waiting time during peak periods;
- growing complexity of patient routing.

These findings are consistent with Lean Healthcare principles, which identify waiting time and process variability as major sources of operational inefficiency [11,12].

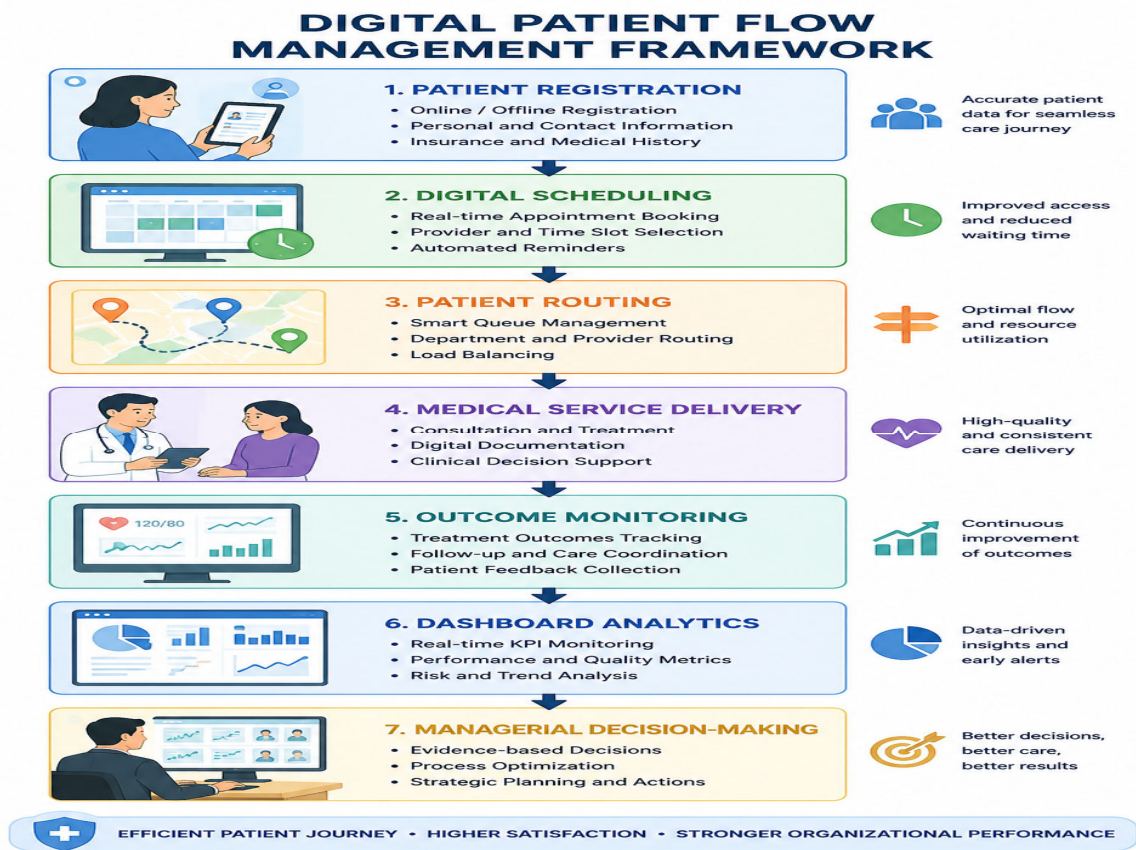


Figure 2 - Digital Patient Flow Management Framework

Source: Author's compilation

Figure 2 demonstrates the integration of digital technologies into patient flow management. Dashboard analytics enables continuous monitoring of patient movement throughout the healthcare process and supports timely interventions aimed at reducing operational bottlenecks.

Workforce Resilience Dashboard

Workforce sustainability remains one of the most critical factors affecting healthcare organizational resilience [13,14,25].

Table 5 Workforce Dashboard Indicators

Indicator	Value
Overall Staffing Completeness	95%
Physician Staffing Completeness	97%
Nursing Staffing Completeness	94%
Workforce Turnover	38%
Physicians with Qualification Category	68%
Nurses with Qualification Category	71%
Source: Author's compilation	

The workforce dashboard presented in Table 5 indicates generally high staffing completeness. However, workforce turnover remains relatively high at 38%, representing a significant organizational risk. Dashboard monitoring allows healthcare managers to track

workforce stability, identify early signs of burnout, and implement retention strategies aimed at strengthening organizational resilience [13,14].

Patient Trust Dashboard

Patient trust has become an increasingly important dimension of healthcare performance evaluation [8,9]. Modern dashboard systems integrate patient-centered indicators into management decision-making processes.

Table 6 Patient Trust Dashboard Components

Indicator	Management Purpose
Net Promoter Score (NPS)	Loyalty assessment
Customer Satisfaction Index (CSI)	Satisfaction monitoring
Patient Complaints	Early warning indicator
Repeat Visits	Trust and retention assessment
Digital Feedback	Reputation monitoring
Source: Author's compilation	

Table 6 presents the Patient Trust Dashboard integrated into the management system of Clinic Miras. The dashboard enables continuous monitoring of patient experience and supports the early identification of reputational risks that may negatively affect organizational sustainability.

Financial Sustainability Dashboard

Financial stability remains a critical component of organizational resilience [6,7,8,20] (Table 7).

Table 7 Financial Dashboard Indicators

Indicator	Strategic Significance
Revenue Dynamics	Financial sustainability
Service Productivity	Operational efficiency
Cost Management	Resource optimization
Patient Retention	Revenue stability
Digital Service Utilization	Innovation performance
Source: Author's compilation	

The financial dashboard supports continuous monitoring of revenue generation, resource utilization, and operational efficiency. The integration of financial indicators with operational and patient-related metrics enhances managerial awareness and improves crisis preparedness [6,7,8].

Integration into the MIRAS-RESILIENCE 7D Framework

The findings of this study formed the basis for the development of the Digital Contour of the MIRAS-RESILIENCE 7D framework.

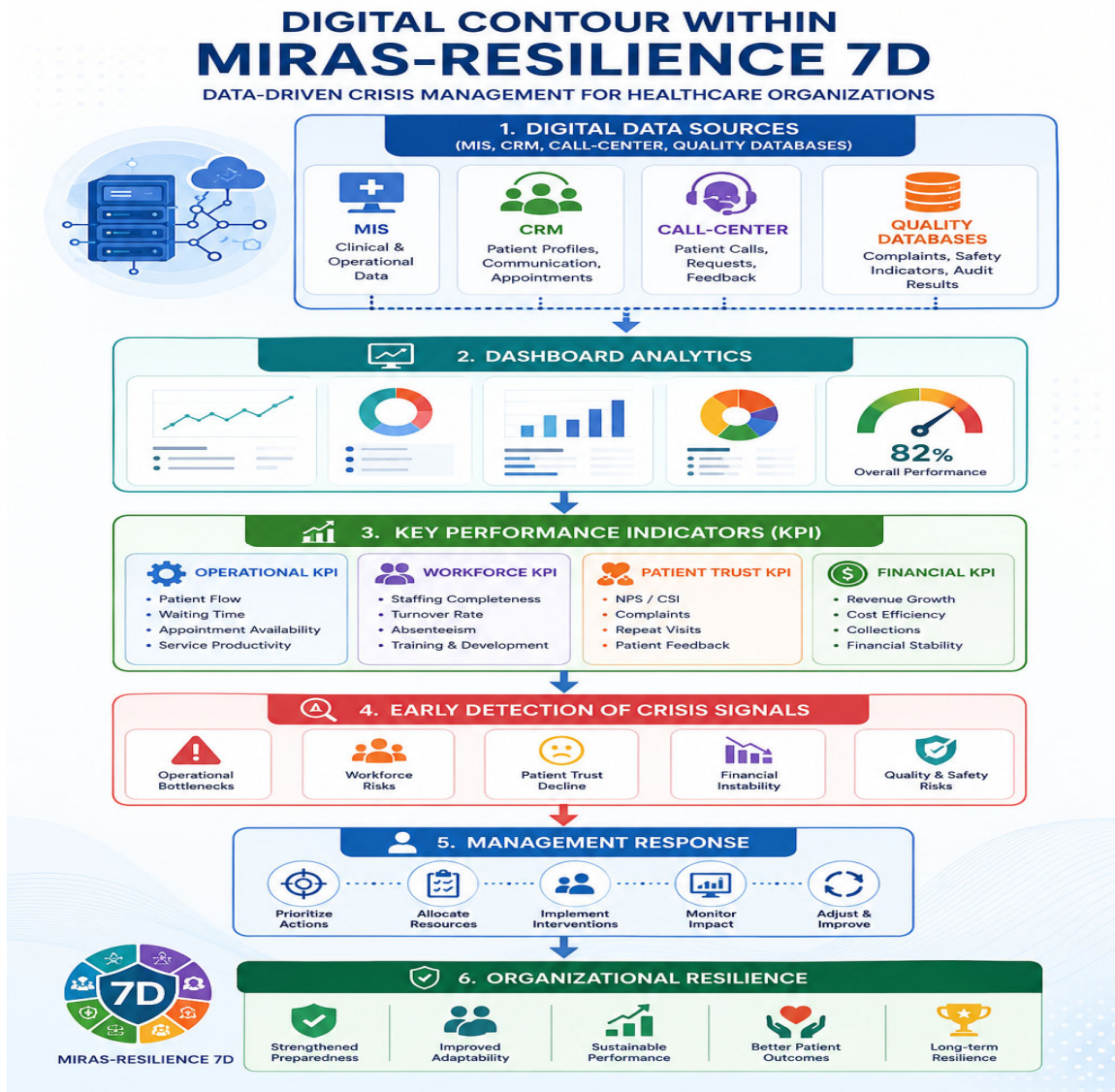


Figure 3 - Digital Contour within MIRAS-RESILIENCE 7D

Source: Author's compilation

Figure 3 illustrates the architecture of the Digital Contour within the MIRAS-RESILIENCE 7D framework. The proposed model transforms Trust fragmented organizational data into a unified analytical environment that supports continuous monitoring, predictive management, and early identification of crisis-related risks [18,19,20,21,25].

The results demonstrate that digital transformation and dashboard analytics represent not only technological innovations but also strategic management tools capable of enhancing organizational resilience, improving operational efficiency, and strengthening crisis preparedness in healthcare organizations. The case of Clinic Miras confirms the practical applicability of dashboard-based management and provides empirical support for the integration of digital analytics into crisis management systems [1,2,3,15,18,25].

6. Conclusions

1. The findings of the study confirm that digital transformation has become a critical determinant of organizational resilience in healthcare organizations. The case of Clinic Miras demonstrates that the integration of digital technologies into management

processes significantly enhances the organization's ability to respond to operational, workforce, financial, and reputational challenges.

2. The analysis revealed a substantial increase in healthcare demand, as evidenced by the growth of the attached population from 13,631 patients in 2019 to 33,357 patients in 2025. This increase of approximately 145% created additional pressure on healthcare resources and highlighted the necessity of implementing digital management tools capable of supporting sustainable organizational growth.
3. Dashboard analytics proved to be an effective management instrument for continuous monitoring of key performance indicators. The integration of operational, workforce, patient trust, quality, digital, and financial indicators into a unified analytical environment improved managerial visibility and facilitated evidence-based decision-making.
4. The implementation of dashboard monitoring enabled the early identification of operational bottlenecks, workforce-related risks, patient experience challenges, and potential threats to organizational performance. The findings demonstrate that dashboard-based management supports a transition from reactive crisis response to proactive and preventive management practices.
5. The study confirmed the strategic importance of patient-centered and workforce-related indicators as components of organizational resilience. Workforce turnover, staffing completeness, patient complaints, service accessibility, and patient trust indicators were identified as critical variables requiring continuous monitoring within healthcare organizations.
6. Based on the empirical evidence obtained from Clinic Miras, the study developed and substantiated the Digital Contour of the MIRAS-RESILIENCE 7D framework. The proposed model integrates digital data sources, dashboard analytics, KPI monitoring, and crisis management mechanisms into a comprehensive early-warning system designed to strengthen organizational resilience.
7. The scientific contribution of the study lies in demonstrating that dashboard analytics should be considered not merely as a technological solution but as a strategic management tool that supports crisis preparedness, operational sustainability, and long-term organizational development in healthcare organizations.
8. The practical significance of the study is reflected in the applicability of the proposed Digital Contour and dashboard-based management approach for healthcare organizations seeking to improve operational efficiency, enhance crisis management capabilities, strengthen patient trust, and increase organizational resilience under conditions of uncertainty and rapidly changing healthcare environments.

The results of this study provide empirical support for the integration of digital transformation initiatives and dashboard analytics into healthcare management systems and contribute to the further development of resilience-oriented management models in healthcare organizations.

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Анатомо-морфометрическая характеристика локализации питательных отверстий бедренной кости человека

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Введение. Питательное отверстие представляет собой небольшое отверстие в кости, через которое в костную ткань входит питающая артерия, обеспечивающая кровоснабжение, рост и процессы окостенения. Питающая артерия длинных костей проходит через питательное отверстие косо и далее следует по питательному каналу в костномозговую полость. Локализация питательных отверстий может изменяться в процессе роста кости, поскольку один из её концов растёт быстрее другого. У взрослых питающий канал имеет единственный наружный выход — питательное отверстие. Сохранение артериального кровоснабжения имеет важное значение для жизнеспособности костной ткани, особенно при проведении реконструктивных операций и использовании васкуляризированных костных трансплантатов. Знание топографии питательных отверстий необходимо для предотвращения повреждения сосудов при выполнении ортопедических и травматологических вмешательств.

Цель исследования. Изучить анатомо-морфометрические особенности питательных отверстий бедренной кости человека, определить их количество, локализацию и размеры.

Материалы и методы. Исследование проведено на 10 препаратах бедренных костей из фонда кафедры нормальной анатомии имени С.Р. Карынбаева Казахского национального медицинского университета имени С.Д. Асфендиярова. Выполнялось визуальное изучение анатомических особенностей питательных отверстий, их локализации и формы. Оценивалась направленность питательных каналов. Все измерения проводились повторно для повышения достоверности полученных результатов.

Результаты. В ходе анатомического и морфометрического исследования установлено, что питательные отверстия бедренной кости преимущественно располагаются на задней поверхности диафиза в области шероховатой линии (*linea aspera*), являющейся местом прикрепления ряда мышц бедра. В 90% исследованных препаратов выявлено одно питательное отверстие, тогда как в 10% случаев обнаружено два отверстия. Средний диаметр питательных отверстий составил от 1 до 3 мм. Следует отметить, что полученные размеры являются ориентировочными, поскольку измерения проводились с

использованием линейки. Во всех исследованных препаратах направление питательных каналов было ориентировано проксимально, в сторону тазобедренного сустава, что соответствует общему анатомическому правилу направления питательных сосудов длинных трубчатых костей нижней конечности — «от колена». Анализ литературных данных показывает, что размеры питательных отверстий могут варьировать в зависимости от возраста, пола и функциональной нагрузки на кость. Длина питательного канала у взрослых обычно составляет 5–10 мм, однако может увеличиваться при высокой физической активности.

Вывод. Проведённое исследование показало, что питательные отверстия бедренной кости имеют определённые закономерности локализации и направления, связанные с особенностями кровоснабжения костной ткани. Наиболее часто они располагаются на задней поверхности диафиза в области шероховатой линии и представлены одним отверстием. Полученные данные имеют практическое значение для травматологии, ортопедии и реконструктивной хирургии, поскольку позволяют учитывать особенности сосудистого обеспечения бедренной кости при планировании оперативных вмешательств.

Journalism

Behind the Glitter of the Floor: The Dark Side of Ballroom Dance

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Abstract: This article examines the development of Dance Sport in the Republic of Kazakhstan through the prism of personal experience. The authors highlight current issues and challenges of this sport, such as lack of funding, societal stereotypes, high tuition fees, judging issues, and the risk of injury.

As a child, my mother brought me to the gym to watch her friend's daughter dance. I was only four years old, but I was so inspired by the atmosphere of the training, the music, and the process itself that I immediately decided it was for me. This sport has given me so much. It taught me how to work in a team, communicate with different people, be disciplined, and strengthened my character. Most importantly, Ballroom Dance developed my sense of taste, an interest in fashion, and all things beautiful. I had to arrive at every training session well-groomed, neat, and put-together.

It is well known that the formation and development of Ballroom Dance in the Republic of Kazakhstan (further - RK) dates back to the second half of the 20th century. The state actively supported the work of dance clubs, coaches, and dancers. Strict sport discipline existed, regulated by judges at National and International Tournaments.

Today, Dance Sport in RK is led by the Association of Dance Sport Federations of the Republic of Kazakhstan (further - ADSF RK) and other specialized organizations accredited by the Ministry of Tourism and Sports. To become a recognized professional dancer in this sport, it is important to hold the titles of "Candidate Master of Sports" (further - CMS) and "Master of Sports of the Republic of Kazakhstan." Leading creative educational institutions in our country, such as the Kazakh National Academy of Choreography in Astana city, the Kazakh National Academy of Arts named after T.K. Zhurgenov in Almaty city, Kazakh National University of Arts (further - KazNUA) - "Shabyt" in Astana city, Almaty Choreographic School named after A.V. Seleznev in Almaty city, and others.

Periodical publications publish articles exploring the development issues, problems, and prospects for the development of this sport. For example, researchers E.S. Moiseyev, R.V. Kenzikeyev, and E.N. Dryagina, in their article "Modern Requirements and Prospects for the Development of Professional Education in Ballroom Dance in Kazakhstan in the Context of Educational and Methodological Literature: Analysis, Trends, and Proposals," drew attention to

the need to develop empirical experience in the field of Ballroom Dance and to update educational, methodological, and specialized literature [1]. Experts A. Isaliev and A. Moldakhmetova developed promising tools for conducting semiotic analysis of dance for wide application in the fields of Dance Sport and in choreographic art [2].

For many years, my cherished dream has been to achieve success in the Dance World, specifically, reaching the professional finals at the Blackpoll Ballroom in England. This legendary competition, held for over a century, is of immense significance to all ballroom dancers. I understand that achieving this goal requires tremendous work and dedication. To achieve this, it's important to take it step by step, setting intermediate goals and constantly evolving. In my opinion, a true champion must be able to use defeats and difficulties as strength for growth, not as a reason to give up. It's also important to be unique, not like everyone else, as Donny Burns said in his lecture, a star of the Dance World.

To get closer to my dream, I train constantly, attend competitions and training camps, investing a lot of time, energy, and resources into it. I recently had the opportunity to travel to England, and it was a major step forward for me because I was able to personally attend a tournament in Blackpool city and experience the atmosphere of a prestigious International Competition where the World's best dancers gather for Dance Sport Competitions. It's especially exciting that this event is taking place in the historic Empress Ballroom in Winter Gardens, renowned for its luxurious interior. Traveling to and participating in a tournament of such international significance motivates me to strive for new goals and achieve my cherished dream, and I believe it will definitely come true.

One of the most memorable experiences of my life was my trip to Italy with my mother for the World Ballroom Dance Championships (further - WBDC). It was both exciting and joyful. We arrived the day before the tournament, so we had time to explore the city. The competition took place in Paestum city, near Naples city. It boasts incredibly beautiful scenery: the sea, trees, and fresh air. The atmosphere was calm and relaxing. The most exciting day, of course, was the tournament itself. I was very nervous, but I managed to pull myself together and achieve a good result. Ultimately, I advanced to the World Championship finals and placed fifth out of 64 competitors. I was very happy and proud of myself. After the tournament, there was a gala evening where everyone danced, socialized, and celebrated. This trip will forever remain etched in my memory because I not only performed well and placed highly, but also spent a wonderful time with my mother. I would really like my mother to take up dance, too, because I believe it's never too late to start. Especially since pro-am dancing is booming now, where professionals dance with beginners or those who simply enjoy the sport. For example, my friend's mother also practices. They train together, and she truly understands how much work and time this sport requires. So, I dream of the day I can dance with my mom!

It's worth noting that good results at such tournaments depend not only on the dancer's personal preparation but also on other factors. These include the high cost of costumes, shoes, and travel to international training camps; finding sponsors to organize large-scale WBDC tournaments within the country; and a shortage of male partners, which is a global trend in this sport.

Dancers with many years of experience, note a lack of time, finances, and constant health care. Unfortunately, in The RK, other sports often receive priority funding. Therefore, despite the development of Ballroom Dance, athletes often have to cover a significant portion of their expenses themselves: costumes, travel, competitions, uniforms, and much more. This can limit the opportunities for talented dancers and create an unequal playing field. Of course, there are sponsors who partner with dancers and make them their ambassadors, but this opportunity is more often available to those who have already achieved some success. Consequently, the less financial resources you have, the less likely you are to achieve great success in this sport. Take the

legendary tournaments in England - a huge number of people come there every year, making a living from this sport and spending large sums of money to participate. After all, without going to such competitions, it's very difficult to gain recognition and reach a higher level. Only participating in tournaments within your own country is often not enough. Achievements in The RK are certainly impressive, but they don't always fully reflect a dancer's level of professionalism. Of course, money isn't always the deciding factor; the most important thing is a strong desire to move forward, develop, and constantly improve.

Many in our country are also hindered by stereotypes, such as "Dance Isn't for Boys". Because of this, many girls remain in the solo category. Some boys quit the sport due to bullying, ridicule from others, or disapproval from relatives. But people new to Ballroom Dance often don't realize how many beneficial qualities the sport develops: discipline, physical endurance, and, for boys, a sense of responsibility for their partner and the couple as a whole. Ballroom Dance isn't just about dancing together; it's about understanding, support, and the ability to navigate through difficult and joyful moments together throughout a career. Furthermore, many dancers quit the sport because of parental reproaches: "Dance Won't feed You". But for many, it becomes their life's purpose - they can't imagine a day without their favorite activity. Not understanding this, some parents rush to convince their teenagers to quit dancing and focus solely on their studies. In our opinion, one doesn't interfere with the other. Many professional dancers successfully combine education and sport. They graduate from good universities with honors and continue to do what they love, which motivates them to keep going. For example, multiple Russian Champion and World Championship finalist Polina Teleshova holds two higher education degrees and is a graduate of Moscow State University and the Moscow Innovation University.

Another problem with Dance Sport is the objectivity of judging. This sport differs from other sports, such as swimming or running, where results are measured by time. Here, everything depends on the judges' opinions and their attitude toward the dancer. Because of this, some feel unfairness and disputes arise around the results. The judge's job is to evaluate an athlete's Dance Performance through comparison. Because of this, dancers constantly compare themselves to others, worrying about results, appearance, weight, partners, rankings, and competition. And at worst, this can lead to scandals between dancers and judges. For example, at the Championship of The RK in Almaty city, where five out of six couples refused to perform in the final [3].

Injuries are also a common problem in Ballroom Dance. Many people think dancing is safe, but professional dancers often experience back, knee, and foot injuries. Collisions on the Dance Floor can also cause injuries to other body parts, as it's an intense dance and it's easy to lose focus.

In conclusion, Ballroom Dance is a unique discipline that combines sport, art, and creativity. Despite the active development of this sport in The RK, dancers still face a number of serious challenges: lack of funding, societal stereotypes, high tuition fees, subjective judging, and the risk of injury. But even these difficulties do not stop people who truly love their work.

Every year, more and more athletes represent Kazakhstan with dignity on the International Stage. For example, Matvey Starikov and Maria Samoylenko are a renowned dance couple from Astana city, The RK, who compete in competitive Ballroom Dance. They made history as the first Kazakhstani couple to win the prestigious championship title at the legendary Blackpool Dance Festival (Blackpool city, The United Kingdom), proving that Ballroom Dance deserves the same attention and respect as other sports. We hope that in the future, this sport will receive even greater support from the government and society, and that talented dancers will be able to realize their potential regardless of financial means and societal stereotypes. After all, behind every appearance on the Dance Floor are years of hard work, discipline, perseverance, and a sincere love for dance.

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Agricultural Sciences

BUĞDA ÇÖRƏYİNİN TƏZƏLİYİNİN QORUNMASINDA DARÇIN EKSTRAKTININ TƏBİİ KONSERVANT KİMİ TƏTBİQİ

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XÜLASƏ

Bu tədqiqat işi buğda çörəyinin təzəliyinin qorunması məqsədilə darçın ekstraktının (Cinnamomum verum) təbii konservant kimi tətbiqinin effektivliyini araşdırır. Müasir istehlakçıların sintetik konservantlara qarşı ehtiyatlı mövqeyi və təbii komponentlərə üstünlük verməsi çörək sənayesində bioinnovativ texnologiyaların inkişafını zəruri etmişdir. Tədqiqatda iki çörək nümunəsi – kontrol (K) və 0,5% darçın əlavəli (D) – eyni resepturada hazırlanmış, hər iki nümunədə nəmlik və turşuluq göstəriciləri standart laboratoriya metodları ilə təyin edilmişdir.

Eksperimental nəticələrə əsasən, darçınli nümunədə nəmlik 38,506% (105°C-də qurutma), turşuluq 2,6°N (0,1 n NaOH titrləmə) təşkil etmişdir. Kontrol nümunədə müvafiq göstəricilər 39,8% və 2,9°N olmuşdur. Hər iki nümunə AZS 18-71-2014 standartına uyğundur. Darçınli nümunə xarakterik aroma və qızılı qəhvəyi qabıq rəngi ilə fərqlənmişdir. Beləliklə, darçın ekstraktının 0,5% dozasında tətbiqi həm elmi, həm də praktiki baxımdan səmərəli yanaşmadır.

Açar sözlər: *Buğda çörəyi, darçın ekstraktı, Cinnamomum verum, təbii konservant, sinamaldehyd, raf ömrü, antimikrob təsir, antioksidant aktivlik, bioinnovativ texnologiya, nəmlik, turşuluq.*

APPLICATION OF CINNAMON EXTRACT AS A NATURAL PRESERVATIVE FOR PRESERVING THE FRESHNESS OF WHEAT BREAD SUMMARY

This research investigates the effectiveness of applying cinnamon extract (Cinnamomum verum) as a natural preservative for preserving wheat bread freshness. The growing cautious attitude of modern consumers toward synthetic preservatives and their preference for natural components has necessitated the development of bio-innovative technologies in the bread industry. In the study, two bread samples – control (K) and with 0.5% cinnamon addition (D) – were prepared with the same recipe, and moisture and acidity indicators were determined for both samples by standard laboratory methods.

According to experimental results, the cinnamon sample showed moisture of 38.506% (drying at 105°C, AOAC 925.10) and acidity of 2.6°N (0.1 n NaOH titration). The control sample showed corresponding indicators of 39.8% and 2.9°N. Both samples comply with AZS 18-71-2014 standard. The cinnamon sample was distinguished by characteristic aroma and golden brown crust color.

Thus, the application of cinnamon extract at 0.5% dose is an effective approach from both scientific and practical perspectives.

Keywords: Wheat bread, cinnamon extract, *Cinnamomum verum*, natural preservative, cinnamaldehyde, shelf life, antimicrobial effect, antioxidant activity, bio-innovative technology, moisture, acidity.

ПРИМЕНЕНИЕ ЭКСТРАКТА КОРИЦЫ В КАЧЕСТВЕ НАТУРАЛЬНОГО КОНСЕРВАНТА ДЛЯ СОХРАНЕНИЯ СВЕЖЕСТИ ПШЕНИЧНОГО ХЛЕБА КРАТКОЕ ОПИСАНИЕ

*В данной работе изучается эффективность применения экстракта корицы (*Cinnamomum verum*) в качестве натурального консерванта для сохранения свежести пшеничного хлеба. Растущее осторожное отношение современных потребителей к синтетическим консервантам и предпочтение натуральных компонентов сделали необходимым развитие биоинновационных технологий. В исследовании два образца хлеба – контрольный (К) и с добавлением 0,5% корицы (Д) – были приготовлены по одинаковой рецептуре, и для обоих образцов определены показатели влажности и кислотности стандартными лабораторными методами.*

Согласно экспериментальным результатам, образец с корицей показал влажность 38,506% (сушка при 105°C, АОАС 925.10) и кислотность 2,6°N (титрование 0,1 н NaOH). Контрольный образец показал соответствующие показатели 39,8% и 2,9°N. Оба образца соответствуют стандарту AZS 18-71-2014. Образец с корицей отличался характерным ароматом и золотисто-коричневым цветом корки. Таким образом, применение экстракта корицы в дозе 0,5% является эффективным подходом как с научной, так и с практической точки зрения.

Ключевые слова: Пшеничный хлеб, экстракт корицы, *Cinnamomum verum*, натуральный консервант, коричный альдегид, срок годности, антимикробное действие, антиоксидантная активность, биоинновационная технология, влажность, кислотность.

GİRİŞ

Son onilliklərdə qida sənayesində sintetik konservantlardan təbii mənşəli alternativlərə keçid əsas tendensiyalardan biridir. Bu dəyişiklik istehlakçıların qida təhlükəsizliyi məsələlərinə artan həssaslığı və “təmiz etiket” konsepsiyasının yayılması ilə bağlıdır. Çörək sənayesində bu xüsusilə əhəmiyyətlidir, çünki çörək gündəlik istehlak məhsulu kimi əhalinin sağlamlığına birbaşa təsir göstərir [1, s. 12]. BMT-nin Ərzaq və Kənd Təsərrüfatı Təşkilatının (FAO) məlumatlarına görə, dünyada hər il istehsal olunan çörəyin təxminən 15-25%-i rəf ömrünün qısa olması səbəbindən tullantıya çevrilir [2, s. 9].

Ənənəvi olaraq çörəyin saxlanma müddətinin uzadılması üçün kalsium propionat, sorbatlar və benzoatlar kimi sintetik konservantlardan istifadə edilir. Bu maddələr effektiv olsa da, müasir tədqiqatlar onların uzunmüddətli istifadəsinin bağırsağ mikrobiotasına mənfi təsir göstərə biləcəyini ortaya qoyur [3, s. 15]. Darçın (*Cinnamomum verum*) min illərdir həm ədviyyat, həm də təbii konservant kimi istifadə edilir. Müasir tədqiqatlar darçındakı sinnamaldehyd, evgenol, sinnamik turşusu və polifenol komponentlərinin güclü antimikrob və antioksidant xüsusiyyətlərə malik olduğunu təsdiqləyir [4, s. 7].

Azərbaycan kontekstində darçının çörək sənayesində istifadəsi xüsusi maraq doğurur. Ölkə üzrə bir nəfərə düşən illik çörək istehlakı təxminən 85 kq təşkil edir və ənənəvi mətbəxdə darçın geniş istifadə olunan ədviyyatdır [5, s. 11]. Bu tədqiqatın məqsədi 0,5% darçın əlavəli buğda çörəyinin əsas keyfiyyət göstəricilərinin nəzarət nümunə ilə müqayisəli qiymətləndirilməsidir.

Tədqiqatın aktuallığı bir neçə amillə müəyyən edilir. Birincisi, qlobal qida sənayesində “təbii və təmiz etiket” konsepsiyası ilə uyğun olan məhsullara tələbat sürətlə artır. İkincisi, Azərbaycan Respublikasının qida təhlükəsizliyi siyasəti çərçivəsində yerli xammal və təbii komponentlərə əsaslanan innovativ texnologiyaların inkişafı prioritet istiqamətdir. Üçüncüsü, çörək itkilərinin azaldılması BMT-nin 2030 Davamlı İnkişaf Məqsədlərindən “Sıfır Aclıq” (SDG 2) və “Məsuliyyətli İstehlak” (SDG 12) hədəflərinə uyğundur. Bu kontekstdə darçın ekstraktının çörəkdə tətbiqi həm ekoloji, həm də iqtisadi baxımdan əsaslandırılmış yanaşmadır.

ƏSAS HİSSƏ

Darçın ekstraktının çörəkdə təbii konservant kimi tətbiqi mexanizmi çoxkomponentlidir. Aktiv komponentlər – sinnamaldehid (65-75%), evgenol (5-10%), sinnamik turşusu (3-7%) və polifenollar (5-8%) – bir-birilə qarşılıqlı şəkildə təsir göstərir. Sinnamaldehid əsas antimikrob agent kimi qiymətləndirilir – onun təsir mexanizmi mikroorqanizm hüceyrə membranının fosfolipid strukturunun pozulmasına və hüceyrə komponentlərinin sızmasına əsaslanır. Sinnamaldehidin *Aspergillus niger* üçün minimum inhibitor konsentrasiyası 250 mq/L səviyyəsində qeyd edilmişdir [4, s. 9].

Polifenol komponentləri darçın ekstraktının antioksidant aktivliyinin əsasını təşkil edir – DPPH testində IC_{50} dəyəri 12-18 μ q/mL arasında qeyd olunmuşdur [6, s. 14]. Çörəkdə darçın ekstraktının tətbiqi üçün üç əsas üsul mövcuddur: xəmirə birbaşa qatılma, çörək səthinə tətbiq və qablaşdırma materialına inteqrasiya. Bu tədqiqatda ən sadə, iqtisadi cəhətdən sərfəli və sənaye miqyasında asanlıqla tətbiq edilə bilən üsul – xəmirə birbaşa qatılma seçilmişdir.

Evgenolun antimikrob təsiri sinnamaldehidi tamamlayır və xüsusilə qram-mənfi bakteriyalara qarşı yüksək effektivlik göstərir. Bu komponentin struktur xüsusiyyətləri ona güclü antifungal aktivlik də verir – xüsusilə *Penicillium citrinum* və *Aspergillus flavus* kimi göbələk növlərinin nəzarətində əhəmiyyətli rola malikdir. Sinnamik turşu isə pH-tənzimləyici funksiyası ilə xəmirin turşuluğunu tənzimləyərək göbələk inkişafının inhibə edilməsi üçün əlverişli mühit yaradır. Bu üç komponentin qarşılıqlı təsiri darçını digər təbii konservantlardan üstün edir.

Darçın ekstraktının funksional qida konsepsiyası baxımından da əhəmiyyətli xüsusiyyətləri vardır. Müasir tədqiqatlar göstərir ki, gündəlik 1-6 q darçın istehlakı qan şəkəri səviyyəsini 18-29% azalda bilər və ürək-damar sağlamlığına müsbət təsir göstərir. Bu xüsusiyyət darçın çörəyin diabetik və prediabetik istehlakçılar üçün xüsusi məhsul kateqoriyası kimi təqdim edilməsinə imkan yaradır, həmçinin xüsusi premium bazar segmentində kommersiya potensialı yüksək məhsullar kateqoriyasına daxil edir.

TƏDQIQAT HİSSƏSİ

Tədqiqat Azərbaycan Dövlət İqtisad Universitetinin (UNEC) qida texnologiyası laboratoriyasında həyata keçirilmişdir. Eksperimentdə iki nümunə hazırlanmışdır: kontrol (K) – adi buğda çörəyi və darçın (D) – ümumi un kütləsinin 0,5%-i miqdarında darçın əlavə edilmiş çörək. Hər iki nümunə eyni xammaldan – birinci növ buğda unu (300 q), içməli su (180 ml, 40°C), quru maya (3 q), duz (5 q), şəkər (4 q) – hazırlanmışdır. Darçın nümunəyə əlavə olaraq 1,5 q toz darçın yoğurma mərhələsində xəmirə birbaşa qatılmışdır. Hər iki xəmir 15 dəqiqə yoğurulmuş, 28°C-də 60 dəqiqə fermentasiya edilmiş, 30 dəqiqə dincəlməyə qoyulmuş və 220°C-də 30 dəqiqə bişirilmişdir.

Çörəklərin hazırlanma protokollarının standartlığı eksperimental nəticələrin etibarlılığı üçün vacib şərtidir. Yoğurma müddətində xəmirin qluten şəbəkəsinin formalaşması, fermentasiya zamanı maya fəaliyyətinin nəticəsində qaz yığılması və bişirmə zamanı qabıq formalaşması – bütün bu mərhələlər, hər iki nümunədə eyni şəraitdə baş vermişdir. Bu, alınan nəticələrdəki fərqlərin yalnız darçın əlavəsi ilə bağlı olduğunu təsdiqləyir.

Vizual qiymətləndirmədə hər iki nümunə yumru forma və qızılı qəhvəyi qabıq müşahidə olunmuşdur. Darçınli nümunə xarakterik darçın aromasına malik olmuş, kəsiyində isə yumşaq tekstura və bərabər paylanmış kiçik məsamələr göstərmişdir.

Nəmlik göstəricisi peşəkar nəmlik analizatoru (Radwag MA 110.R.WH) vasitəsilə təyin edilmişdir. Nümunə 105°C temperaturda sabit çəkiyə qədər qurudulur. Hər nümunədən təxminən 3 q xırdalanmış çörək içi alüminium taraya qoyulmuş və 22 dəqiqə 30 saniyə müddətində qurutmaya məruz qalmışdır.

Turşuluq 0,1 n NaOH məhlulu ilə titrləmə üsulu vasitəsilə təyin edilmişdir. Hər nümunədən 25 q çörək içi götürülmüş (Radwag AS 220.R1 plus analitik tərəzisi), şüşə qaba qoyulmuş, üzərinə 250 ml su əlavə edilərək 2 dəqiqə çalxalanmış və 10 dəqiqə saxlanılmışdır. Süzülmüş mayedən 50 ml götürülərək konusvari kolbaya tökülmüş, fenolftalein indikatoru əlavə edilərək 0,1 n NaOH məhlulu ilə titrlənmişdir. Hesablama düsturu:

$$X = 2 \times Y \times K$$

burada Y – titrəyə sərf olunan NaOH məhlulu (ml), K – normallıq əmsali (K=1). Eksperimental nəticələr Cədvəl 1-də təqdim olunmuşdur.

Cədvəl 1. Kontrol və darçınli çörək nümunələrinin əsas keyfiyyət göstəricilərinin müqayisəsi

Göstərici	Kontrol nümunə (K)	Darçınli nümunə (D, 0,5%)	AZS 18-71-2014 norması
Nəmlik, %	39,8	38,506	38–44
Turşuluq, °N	2,9	2,6	≤ 3,0
Forma və görünüş	Yumru, hamar	Yumru, parlaq	Düzgün
Qabıq rəngi	Açıq qəhvəyi	Qızılı qəhvəyi	Qızılı qəhvəyi
İç teksturası	Yumşaq	Yumşaq, elastik	Yumşaq
Aroma	Neytral çörək	Xarakterik darçın	Standart

Cədvəl 1-dən göründüyü kimi, hər iki nümunənin əsas keyfiyyət göstəriciləri AZS standartının tələblərinə tam uyğundur. Qeyd etmək lazımdır ki, darçınli nümunədə turşuluq göstəricisi (2,6°N) kontrol nümunədən (2,9°N) bir qədər aşağıdır. Bu nəticə darçındakı sinnerin turşusunun pH-tənzimləyici təsirinə işarə edir və göbələk inkişafının qarşısının alınması üçün əlverişli mühit yaradır [7, s. 16]. Nəmlik göstəricilərinin müqayisəsi göstərir ki, darçınli nümunədə nəmlik 1,3% aşağıdır – bu darçındakı polisaxarid komponentlərinin (mannan, qalaktomannan) hiqroskopik təsirinə bağlıdır.

Aşağı nəmlik göstəricisi mikrobioloji baxımdan üstünlükdür – su aktivliyinin (aw) azalması göbələk və bakteriyaların inkişafı üçün əlverişsiz mühit yaradır. Kontrol nümunədə daha yüksək nəmlik (39,8%) tipik buğda çörəyinin xarakterik göstəricisidir, lakin uzunmüddətli saxlanma zamanı bu, mikrobioloji pozulma riskini artırır. Darçınli nümunədə isə 38,506% nəmlik dərəcəsi həm təzəlik hissini saxlayır, həm də qida təhlükəsizliyini təmin edir – bu balanslı nəticədir.

Turşuluq göstəricilərinin müqayisəli analizi də əhəmiyyətlidir. Çörəkdə turşuluq dad keyfiyyəti, mikrobioloji sabitlik və qida təhlükəsizliyi üçün kritik göstəricidir. Standart həddən (3,0°N) yuxarı turşuluq dad pisləşməsinə, aşağı turşuluq isə mikrobioloji riskə səbəb ola bilər. Hazırlanmış nümunələrin hər ikisində turşuluq optimal həddədir, lakin darçınli nümunədə bir qədər aşağı qeydiyyata alınması orqanoleptik baxımdan xeyirli haldır.

Aparılan eksperimental tədqiqatın əsas nəticələri aşağıdakılardır: hər iki nümunə AZS 18-71-2014 standartına uyğundur; darçın əlavəsi xəmirin strukturuna mənfi təsir göstərmir; darçınli nümunədə

turşuluq daha aşağıdır (2,6°N və 2,9°N) – bu mikrobioloji sabitlik üçün üstünlükdür; darçınli nümünə xarakterik aroma və qızılı qabıq rəngi ilə əlavə dəyər təqdim edir; texnologiya əlavə avadanlıq tələb etmir.

Əlavə müşahidə kimi qeyd etmək lazımdır ki, hazırlanmış darçınli çörək nümunəsi vizual baxımdan kontrol nümunədən daha cəlbedici görünüşə malikdir – qızılı qəhvəyi parlaq qabıq və xarakterik darçın aroması məhsulun istehlakçı qəbulunu artıran amillərdir. Maillard reaksiyaları zamanı darçındakı şəkər-amin qarşılıqlı təsirləri qabıq rəngini intensivləşdirir, bu isə premium məhsul kateqoriyasında bazar üstünlüyü yaradır. Eyni zamanda darçınli çörəkdə hiss olunan aromatik komponentlər – sinnamaldehidin uçucu təsiri – istehlakçıların məmnuniyyət dərəcəsini yüksəldir.

NƏTİCƏ

Nəticə olaraq aparılan eksperimental tədqiqat darçın ekstraktının (*Cinnamomum verum*) 0,5% dozasında buğda çörəyində təbii konservant kimi uğurla tətbiq edilə bildiyini təsdiqləmişdir. UNEC qida texnologiyası laboratoriyasında həyata keçirilmiş analitik qiymətləndirmənin nəticələri – darçınli nümünədə nəmlik 38,506% və turşuluq 2,6°N, kontrol nümunədə nəmlik 39,8% və turşuluq 2,9°N – AZS 18-71-2014 standartının tələblərinə tam uyğundur. Darçındakı bioaktiv komponentlərin – sinnamaldehid, evgenol, sinnamik turşusu və polifenollar – çoxmexanizmlı antimikrob və antioksidant təsiri elmi ədəbiyyatda təsdiq olunmuşdur [8, s. 13].

Praktiki baxımdan tədqiqatın nəticələri Azərbaycan çörək sənayesi üçün əhəmiyyətli perspektiv yaradır. Darçın ekstraktının xəmirə birbaşa qatılması üsulu əlavə avadanlıq tələb etmir, ənənəvi çörək istehsal prosesinə asanlıqla inteqrasiya olunur və yerli istehlakçılar tərəfindən qəbul edilməyə hazırdır. Eyni zamanda darçınli çörəyin funksional qida kimi təqdim edilməsi premium bazar segmentində əlavə dəyər qatır.

Tədqiqatın elmi əhəmiyyəti məhsulun keyfiyyət göstəricilərinin standartlara uyğunluğu və darçındakı bioaktiv komponentlərin qarşılıqlı təsirinə təsdiqlənməsindən ibarətdir. Eksperimental nəticələrin elmi ədəbiyyatda təqdim olunan məlumatlarla uyğunluğu bu yanaşmanın etibarlılığını göstərir. Gələcək tədqiqatlarda darçın ekstraktının digər təbii konservantlarla — qranat qabığı ekstraktı, rozmarin və yaşıl çay polifenolları — sinerjik kombinasiyalarının öyrənilməsi, mikroenkapsulyasiya texnologiyalarının tətbiqi və saxlanma müddətinin dinamikasının (3, 5, 7 və 10-cu günlərdə) izlənməsi perspektivli istiqamətlər kimi qiymətləndirilir.

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Yield and correlation indices of Chinese buckwheat varieties with the local standard in the conditions of the Akmola region

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Introduction. Buckwheat (*Fagopyrum esculentum* Moench.) is a plant species belonging to the Polygonaceae family and represents one of the earliest crops domesticated in Asia. Historically, it served as an important food source and was extensively cultivated and consumed between the 17th and 19th centuries. Its cultivation and consumption later declined in many Western countries as wheat became the dominant cereal crop. In recent decades, however, growing interest in healthy diets and functional foods has renewed attention to buckwheat due to its exceptional nutritional qualities. Today, it is widely recognized as a nutrient-rich pseudocereal with considerable potential for future food systems.

Compared with many traditional cereal crops, buckwheat contains higher levels of valuable nutrients and bioactive compounds, including rutin, dietary fiber, iron, and various essential micronutrients. Its grains are naturally gluten-free and provide a favorable amino acid profile, particularly because of their relatively high lysine content. In addition, buckwheat is capable of growing on relatively poor soils and therefore can be cultivated under conditions where other crops may perform less successfully. Nevertheless, its productivity can be significantly affected by adverse environmental conditions such as frost, low temperatures, heat stress, dry winds, and drought.

Yield is a key criterion in the evaluation and selection of new buckwheat varieties for agricultural production, where a statistically proven yield advantage of at least 20% over the standard is a mandatory requirement for the introduction of a new variety.

As one of the most valuable characteristics, this indicator reflects the realization of a plant's biological potential under specific conditions, simultaneously demonstrating the adaptability, plasticity, and stability of a variety. Since the primary goals of agriculture are to achieve maximum

yield while ensuring high seed quality and maintaining soil fertility, an objective assessment and successful introduction of varieties requires not only optimizing all controllable plant factors but also considering the impact of unpredictable natural conditions.

Materials and methods. The study was carried out using common buckwheat (*Fagopyrum esculentum* Moench) accessions of Chinese origin. The variety Shortandinskaya coarse-grained served as the standard reference. Field experiments were performed following the methodology developed by B.A. Dospekhov at the A.I. Barayev Scientific and Production Center for Grain Farming. The collection nursery was established by manual sowing on the 28th of May. Each experimental plot covered an area of 2 m². Accessions were arranged systematically, with the standard variety included after every ten entries. The distance between rows was maintained at 20 cm, while plants within rows were spaced 5 cm apart. Seeds were sown at a depth of 5 cm. The experimental plots within the collection nursery were organized according to a systematic layout.

Results. The yield indicators of the variety samples examined in the study are presented in Table 1.

Table 1 - Yield of buckwheat varieties

No.	Name of varieties	Yield, g	+/- deviation from standard
1	Shortandinskaya coarse-grained st.	422.6	-
2	9978 (XN-9978)	251.6	-17.1
3	T1208 (XN-T1208)	221	-20.1
4	T1211 (XN-T1211)	179	-24.3
5	T1311 (XN-T1311)	245.6	-17.7
6	T1925 (XN-T1925)	168.6	-25.4
7	Southern Chinese	43.6	-37.9
8	Chinese Domestic	86	-33.6

An analysis of the presented yield data for buckwheat varieties revealed significant differences between the studied varieties, reflecting their varying degrees of adaptation to the region's soil and climatic conditions. The local standard, Shortandinskaya coarse-grained st., emerged as the absolute leader in yield, achieving 422.6 g/m² (equivalent to 42.26 c/ha). This yield significantly exceeded that of all introduced varieties, confirming its high environmental sustainability and production stability in the Akmola region.

Among the introduced forms, the highest yield values were observed in samples 9978 (XN-9978) - 251.6 g / m² and T1311 (XN-T1311) - 245.6 g / m². Despite the fact that these samples are inferior to the standard by 171 and 177 g / m², respectively, they demonstrate a relatively high level of productivity compared to other introduced varieties, which allows us to consider them promising for further breeding work. Somewhat lower indicators were obtained for sample T1208 (XN-T1208), the yield of which amounted to 221 g / m², deviating from the standard by 201.6 g / m². Sample T1211 (XN-T1211) was characterized by even lower productivity - 179 g / m², which indicates a limited realization of its potential in the given conditions.

The least productive of the studied forms were the T1925 (XN-T1925) samples - 168.6 g/m², as well as varieties of Chinese origin. In particular, Southern Chinese demonstrated an extremely low yield of 43.6 g/m² (deviation from the standard of -379 g/m²), and Chinese Domestic - 86 g/m² (-336.6 g/m²). These results indicate a significant inadequacy for the harsh continental climate of Northern Kazakhstan, likely due to insufficient resistance to temperature fluctuations, droughts, and other abiotic stresses.

Overall, it was established that the introduced accessions, despite some morphological

advantages, are significantly inferior to the local standard in terms of actual yield. This highlights the key role of genotype adaptability in yield formation. At the same time, the identification of individual accessions, such as 9978 and T1311, with relatively high productivity indicators, demonstrates the feasibility of their further use in breeding programs to create new, more adapted and high-yielding buckwheat varieties for the conditions of northern Kazakhstan.

In this regard, within the framework of the study, the correlation by Pearson between the characteristics associated with the yield structure of buckwheat varieties was calculated and assessed using the R Studio program (Figure 1).

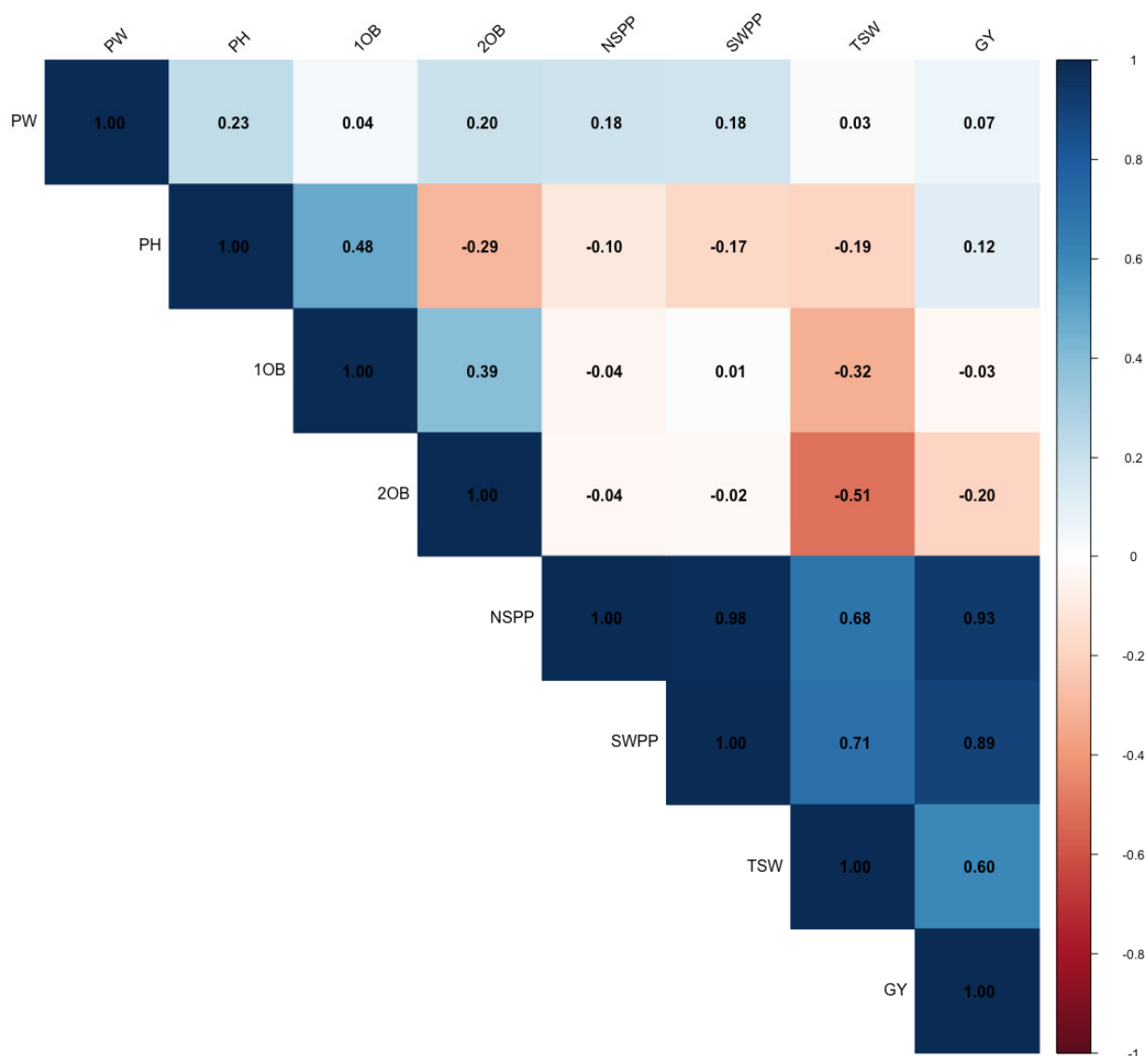


Figure 1. Correlation between the elements of the buckwheat yield structure. PW - plant weight (g), PH - plant height (cm), B1 - first-order branching (pcs), B2 - second-order branching (pcs), NSP - number of grains per plant (pcs), SWP - grain weight per plant (g), TSW - weight of 1000 seeds (g), GY - yield (g).

The analysis revealed close functional relationships between yield and a number of structural elements. A very high positive correlation was found between yield (GY) and the number of grains per plant (NSP, $r = 0.93$), as well as the grain weight per plant (SWP, $r = 0.89$), confirming the decisive role of these traits in determining the final productivity of buckwheat. A moderate positive relationship was also noted between yield and thousand-seed weight (TSW, $r = 0.60$),

indicating an additional, albeit less pronounced, influence of grain size on overall yield.

In contrast, the relationship between yield and total plant weight (PW) was extremely weak ($r = 0.07$), indicating an inefficient conversion of accumulated vegetative biomass into generative products. This fact highlights that intensive development of aboveground mass is not always accompanied by an adequate increase in grain productivity.

The nature of the relationships associated with the number of grains per plant deserves special attention. This indicator was found to be closely correlated with grain weight (SWP, $r = 0.98$) and, to a lesser extent, with thousand-seed weight (TSW, $r = 0.68$), confirming its key role as the primary factor determining yield. At the same time, traits associated with branching showed a different direction of relationships: the number of second-order branches (B2) is characterized by a moderate negative correlation with thousand-seed weight ($r = -0.51$) and a weak negative relationship with yield ($r = -0.20$). This suggests that excessive branching in this region leads to a redistribution of plastic substances in favor of vegetative organs, reducing the efficiency of grain filling and formation.

Conclusion. Thus, the obtained results indicate that the priority in breeding the studied samples should be increasing the number of full-fledged grains per plant while simultaneously optimizing plant architecture, particularly branching. Implementing this approach will improve the efficiency of assimilates and, consequently, ensure increased yields, offsetting the identified gap between the introduced varieties and the local standard.

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Political Studies

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THE ECONOMIC AND SOCIAL IMPACT OF THE COVID-19 PANDEMIC ON CENTRAL ASIA: A COMPARATIVE ANALYSIS OF FIVE STATES

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Аңдатпа. Бұл мақалада COVID-19 пандемиясының Орталық Азияның бес мемлекетіне (Қазақстан, Өзбекстан, Қырғызстан, Тәжікстан, Түрікменстан) тигізген экономикалық және әлеуметтік салдарлары салыстырмалы талдау негізінде зерттеледі. ЖІӨ динамикасы, еңбек нарығының өзгерістері, шағын және орта бизнеске тигізген зиян, аударым ақшалары мен кедейшілік деңгейі сияқты негізгі макроэкономикалық және әлеуметтік көрсеткіштер талданады. Зерттеу пандемияның аймақтағы елдер арасындағы экономикалық теңсіздікті тереңдеткенін, ал ең осал топтар — еңбекші мигранттар, шағын бизнес өкілдері және ауылдық халық — екенін дәлелдейді.

Түйін сөздер: COVID-19, Орталық Азия, экономикалық салдарлар, еңбек нарығы, аударым ақшалары, кедейшілік, шағын және орта бизнес, салыстырмалы талдау.

Аннотация. В данной статье на основе сравнительного анализа исследуются экономические и социальные последствия пандемии COVID-19 для пяти государств Центральной Азии (Казахстан, Узбекистан, Кыргызстан, Таджикистан, Туркменистан). Анализируются ключевые макроэкономические и социальные показатели: динамика ВВП, изменения на рынке труда, ущерб малому и среднему бизнесу, уровень денежных переводов и бедности. Исследование доказывает, что пандемия углубила экономическое неравенство между странами региона, а наиболее уязвимыми группами оказались трудовые мигранты, представители малого бизнеса и сельское население.

Ключевые слова: COVID-19, Центральная Азия, экономические последствия, рынок труда, денежные переводы, бедность, малый и средний бизнес, сравнительный анализ.

Abstract. This article examines the economic and social consequences of the COVID-19 pandemic for the five states of Central Asia — Kazakhstan, Uzbekistan, Kyrgyzstan, Tajikistan and Turkmenistan — through a comparative analytical framework. Key macroeconomic and social indicators are analyzed, including GDP dynamics, labor market disruptions, damage to small and medium-sized enterprises, remittance flows, and poverty rates. The study demonstrates that the pandemic deepened economic inequality among the countries of the region, with the most vulnerable groups identified as labor migrants, small business owners, and rural populations.

Keywords: COVID-19, Central Asia, economic consequences, labor market, remittances, poverty, small and medium enterprises, comparative analysis.

1. INTRODUCTION

The COVID-19 pandemic, declared by the World Health Organization in March 2020, triggered an unprecedented global socioeconomic crisis. Few regions experienced its impact as acutely as Central Asia — a geopolitically complex zone comprising five post-Soviet states: Kazakhstan, Uzbekistan, Kyrgyzstan, Tajikistan, and Turkmenistan. These countries, while sharing historical and cultural ties, differ substantially in their economic structures, institutional capacities, and degrees of integration into global markets, making the region an ideal laboratory for comparative pandemic impact research.

The five Central Asian economies vary widely in their resilience. Kazakhstan, with its hydrocarbon-driven economy, represents the region's largest and most diversified GDP. Uzbekistan has undergone significant economic liberalization since 2016. Kyrgyzstan and Tajikistan remain heavily dependent on labor remittances, while Turkmenistan operates a largely closed, state-controlled economy with limited transparency on official statistics. This heterogeneity means that while all five states faced the same external shock, the magnitude and nature of their economic and social responses diverged considerably [1].

Previous pandemics — notably SARS (2003) and the H1N1 influenza (2009) — provided limited precedents for Central Asian policymakers, as their economic integration into global supply chains was far less developed at those times. The COVID-19 crisis thus represented an unprecedented stress test for the region's institutions, social safety nets, and economic governance [2].

The research objective of this article is to conduct a systematic comparative analysis of the economic and social consequences of the COVID-19 pandemic across all five Central Asian states, identify structural vulnerabilities exposed by the crisis, and draw lessons relevant to future pandemic preparedness and socioeconomic resilience. The article addresses the following research questions: How did the pandemic affect GDP and macroeconomic stability in each of the five states? What were the differential effects on labor markets and remittance-dependent households? How did the pandemic reshape the landscape of small and medium enterprises (SMEs)? What social groups were most severely impacted, and what policy responses were most effective?

The article is structured as follows: Section 2 reviews the theoretical and methodological framework; Section 3 analyzes macroeconomic consequences; Section 4 examines labor market and remittance effects; Section 5 discusses SME disruption; Section 6 explores social and welfare impacts; Section 7 evaluates government responses; and Section 8 presents conclusions and policy recommendations.

2. THEORETICAL FRAMEWORK AND METHODOLOGY

This study draws on three complementary theoretical lenses. First, the framework of economic resilience — defined as a country's capacity to absorb, adapt, and recover from shocks — provides the overarching analytical perspective [3]. Resilience theory distinguishes between engineering resilience (speed of recovery to the pre-shock equilibrium) and ecological resilience (the capacity to adapt and transform in response to new conditions). The COVID-19 pandemic tested both dimensions in Central Asian economies.

Second, the concept of vulnerability is employed to identify structural characteristics that amplify pandemic impact. Vulnerability in this context is understood as the degree to which economic systems and social groups are susceptible to harm from the pandemic shock, shaped by factors such as economic diversification, institutional quality, social protection coverage, and access to global financial systems [4]. Third, comparative political economy provides the analytical method for cross-national comparison, allowing the identification of both common regional patterns and country-specific divergences.

The methodology combines quantitative and qualitative approaches. Quantitative data is drawn from the World Bank, IMF World Economic Outlook databases, Asian Development Bank country reports, and national statistical agencies (where available and reliable). Particular caution is applied to Turkmenistan's official statistics, which are widely considered to underreport economic difficulties. Qualitative analysis draws on reports from international organizations, academic literature published between 2020 and 2024, and policy documents from national governments. The comparative framework follows a most-similar-systems design, leveraging the shared post-Soviet institutional heritage of the five states while examining variation in outcomes.

3. MACROECONOMIC CONSEQUENCES: GDP, TRADE AND FISCAL PRESSURES

The macroeconomic shock of COVID-19 manifested across Central Asia through three primary channels: collapse of commodity prices (particularly affecting Kazakhstan and Turkmenistan), disruption of global and regional trade flows, and contraction of domestic demand due to lockdown measures. The cumulative effect produced the most severe GDP contractions the region had experienced since the economic crises of the early post-Soviet transition period.

Kazakhstan, the region's largest economy, recorded a GDP contraction of approximately 2.6% in 2020, compared to average growth of 4–5% in preceding years [5]. The collapse of oil prices in the first half of 2020 — when Brent crude fell below \$25 per barrel in April 2020 — directly impacted the national budget, which was heavily dependent on hydrocarbon revenues. The government was compelled to draw on the National Fund (sovereign wealth fund), deploying approximately \$10 billion USD in counter-cyclical expenditure to stabilize the economy. Recovery was relatively swift, with GDP growth rebounding to 4% in 2021, underpinned by rising commodity prices and pent-up domestic demand.

Uzbekistan experienced a notable deceleration rather than outright contraction, with GDP growth slowing to 1.6% in 2020 from 5.8% in 2019 [6]. The Uzbek government's reform agenda — including currency liberalization and private sector development launched under President Mirziyoyev — provided a degree of institutional flexibility, though the pace of reform was inevitably disrupted. The service sector, particularly tourism and hospitality, contracted sharply.

Kyrgyzstan and Tajikistan experienced the most severe macroeconomic downturns in relative terms. Kyrgyzstan's GDP contracted by 8.4% in 2020, the steepest decline in the region, reflecting the country's extreme openness and dependence on trade, tourism, and remittances [7]. The Dordoi and Kara-Suu bazaars — central nodes of the informal trade economy — were shuttered for extended periods, devastating merchants and logistics networks. Tajikistan's officially reported GDP growth of 4.5% in 2020 is widely regarded as statistically implausible given the severity of the economic disruptions observed, suggesting significant underreporting [8].

Turkmenistan, operating a largely state-directed economy with extremely limited external transparency, claimed positive GDP growth throughout the pandemic period. Independent analysts and the IMF have expressed serious reservations about these figures. The collapse of natural gas export revenues — particularly from the China–Central Asia pipeline — almost certainly imposed severe fiscal pressures that were not reflected in official statistics.

Table 1. GDP Growth Rates in Central Asian Countries, 2019–2022 (%)

Country	2019	2020	2021	2022
Kazakhstan	4.5	-2.6	4.0	3.2
Uzbekistan	5.8	1.6	7.4	5.7
Kyrgyzstan	4.6	-8.4	3.6	7.0
Tajikistan	7.4	4.5*	9.2	8.0
Turkmenistan	6.3	5.9*	6.2*	6.1*

* Figures subject to significant statistical uncertainty. Sources: World Bank, IMF WEO 2023.

Fiscal pressures emerged as a common challenge across the region. All five governments faced simultaneous demands for increased health expenditure, social protection payments, and economic stimulus, at a time when revenues from trade, taxation, and commodity exports were declining. The fiscal response capacity varied significantly: Kazakhstan and, to a lesser extent, Uzbekistan had access to fiscal buffers, while Kyrgyzstan and Tajikistan required emergency support from the IMF and multilateral development banks.

4. LABOR MARKETS, MIGRATION AND REMITTANCE SHOCKS

Perhaps no single economic channel transmitted the COVID-19 shock more powerfully in Central Asia than the collapse of labor migration and associated remittance flows. The region is home to millions of labor migrants working primarily in Russia and Kazakhstan, whose remittances constitute a critical component of household income in Kyrgyzstan and Tajikistan, and a significant one in Uzbekistan.

When Russia and Kazakhstan imposed border closures and lockdown measures in March–April 2020, the flow of migrant workers was abruptly severed. Hundreds of thousands of Central Asian migrants were stranded — either unable to return home or unable to work in host countries. According to the World Bank, remittances to Kyrgyzstan fell by approximately 12% in 2020 compared to 2019, while Tajikistan recorded a decline of around 9% [9]. In Uzbekistan, where the reform agenda had begun to formalize the migrant labor sector, the contraction was partially cushioned by improved institutional frameworks but remained severe.

The consequences for receiving households were immediate and profound. In Kyrgyzstan, remittances constitute approximately 25–30% of GDP — one of the highest ratios globally — meaning that a sudden contraction in these flows translated directly into increased household poverty rates, reduced consumption, and withdrawal of children from private educational institutions [10]. Rural households, which rely disproportionately on remittance income, were particularly severely affected.

Domestic labor markets also experienced significant stress. Informal employment — which constitutes a substantial share of total employment across all five states — offered minimal protection to workers facing unemployment. The ILO estimated that informal workers in Central Asia lost between 60–80% of their incomes during peak lockdown periods in 2020 [11]. Formal unemployment statistics, where available, understated the true extent of labor market disruption due to the prevalence of informal and self-employment arrangements.

Gender dimensions of labor market disruption deserve particular attention. Women in Central Asia are disproportionately represented in sectors most severely affected by pandemic restrictions: retail trade, hospitality, education, and healthcare. The closure of schools and care facilities simultaneously increased unpaid domestic care burdens, predominantly borne by women, further constraining their labor market participation. Survey data from Kazakhstan and Kyrgyzstan indicated that female-headed households experienced poverty increases approximately 15–20% higher than the regional average [12].

Table 2. Remittance Flows to Central Asian Countries (% of GDP), 2019–2021

Country	2019 (%)	2020 (%)	2021 (%)	Change 2019–20
Kazakhstan	0.2	0.2	0.3	Stable
Uzbekistan	14.8	13.1	17.3	▼ -1.7%
Kyrgyzstan	29.2	25.8	31.6	▼ -3.4%
Tajikistan	27.4	24.9	28.8	▼ -2.5%
Turkmenistan	N/A	N/A	N/A	N/A

Sources: World Bank Remittance Data, 2022; KNOMAD database.

5. IMPACT ON SMALL AND MEDIUM ENTERPRISES

Small and medium enterprises (SMEs) form the backbone of Central Asian economies in terms of employment generation, though their contribution to formal GDP is constrained by the prevalence of informality. The pandemic inflicted severe damage on this sector through multiple mechanisms: forced closure of non-essential businesses during lockdowns, collapse of consumer demand, supply chain disruptions, and acute credit market stress as lenders tightened conditions.

In Kazakhstan, government surveys conducted in mid-2020 found that over 40% of SMEs had temporarily ceased operations, and approximately 15% reported that they did not expect to resume activities [13]. The tourism, hospitality, events, and retail sectors were decimated. The government launched the Economy of Simple Things program and Zerde digital economy initiative as part of a broader recovery package, providing subsidized loans and tax deferrals to qualifying SMEs.

Uzbekistan's SME sector, which had benefited from recent liberalization reforms, faced significant liquidity crises. The government introduced a package of tax holidays, loan restructuring, and direct support payments for businesses in affected sectors. However, access to formal financial services remained uneven, with rural and informal businesses largely excluded from official support mechanisms [14].

In Kyrgyzstan, the impact on SMEs was compounded by the country's political instability — the government changed three times between 2020 and 2021 — which disrupted the consistency of economic support measures. The informal bazaar economy, which employs a large share of the urban working population, received minimal formal support and relied on community-based mutual aid networks.

A significant concern emerging from the pandemic is the risk of increased market concentration. As SMEs collapsed or contracted, larger enterprises — particularly those with access to digital platforms — were able to expand their market share. E-commerce grew rapidly across the region, but the benefits were concentrated among established players and urban consumers with reliable internet access, deepening rural-urban economic divides [15].

6. SOCIAL CONSEQUENCES: POVERTY, INEQUALITY AND WELFARE

The economic disruptions caused by the pandemic translated into measurable social regression across Central Asia, reversing years of progress on poverty reduction and human development indicators. The World Bank estimated that the COVID-19 pandemic pushed an additional 2–3 million people in Central Asia into poverty (defined as living below \$3.20/day PPP) in 2020 alone, with the majority located in Kyrgyzstan, Tajikistan, and the poorer provinces of Uzbekistan [16].

Pre-existing social vulnerabilities amplified the pandemic's social impact. In Tajikistan, where approximately one-third of the population lived near the poverty line even prior to 2020, the combination of remittance decline and economic contraction created acute food security risks. UNICEF data indicated a measurable increase in child malnutrition indicators in the country's mountainous Gorno-Badakhshan region during 2020–2021 [17].

Healthcare system stress was a defining feature of the social impact. Central Asian healthcare systems — which were historically underfunded and structurally weakened by post-Soviet privatization — were rapidly overwhelmed by COVID-19 caseloads. Kazakhstan and Uzbekistan, with relatively stronger institutional capacity, were able to mobilize emergency hospital capacity more effectively. Kyrgyzstan and Tajikistan experienced severe shortages of oxygen, intensive care beds, and personal protective equipment, resulting in excess mortality estimates that significantly exceeded official COVID-19 death tolls [18].

Education emerged as a critical social vulnerability. As detailed in the context of the dissertation's third chapter, the shift to distance learning exposed deep digital divides within and between Central Asian states. Dropout rates increased, particularly among girls in rural areas and children from households experiencing poverty. UNESCO estimates suggest that learning losses accumulated during 2020–2021 may require 3–5 years of targeted remedial educational investment to address [19].

Social protection systems faced unprecedented demands during the pandemic. All five governments introduced emergency social assistance measures of varying scope. Kazakhstan launched the largest program, with one-time payments of 42,500 tenge to individuals who had lost income — a measure that reached over 4.5 million people. Uzbekistan expanded its Makhalla committee-based social support system. However, in all five countries, the informal economy's workers and those without formal employment records were systematically excluded from most support programs [20].

7. GOVERNMENT RESPONSES AND COMPARATIVE POLICY EFFECTIVENESS

Government responses to the pandemic across the five Central Asian states varied considerably in terms of speed, scale, transparency, and effectiveness, reflecting underlying differences in institutional capacity, fiscal space, and political systems.

Kazakhstan implemented the most comprehensive response package, mobilizing approximately 9 trillion tenge (roughly \$21 billion USD) in anti-crisis measures, equivalent to approximately 13% of GDP [21]. The package combined health system investments, direct social transfers, SME support, and infrastructure stimulus. The government also launched the STOP COVID-19 national tracking application and pursued a rapid vaccination campaign, achieving 60% adult vaccination coverage by end-2021.

Uzbekistan's response was notable for its use of the existing Makhalla (community council) network as a social protection delivery mechanism, blending modern administrative instruments with traditional community governance structures. This hybrid approach enabled relatively rapid identification and support of vulnerable households, though it also raised concerns about political supervision of civil society.

Kyrgyzstan's response was severely constrained by fiscal limitations and political instability. The government declared a State of Emergency in March 2020 but lacked the resources to enforce sustained lockdowns or provide meaningful economic support at scale. International financial support — including emergency IMF disbursements and loans from the Asian Development Bank — was critical in stabilizing the fiscal situation.

Tajikistan's response was characterized by an initial denial of significant community transmission, with the government only acknowledging widespread COVID-19 cases in May 2020. This delayed response likely contributed to accelerated community spread and excess mortality. The government's limited fiscal resources and institutional capacity constrained the scope of economic support measures. Turkmenistan similarly denied any significant COVID-19 presence on its territory throughout the pandemic period, a position that severely limited the government's ability to mount an evidence-based public health and economic response [22].

Comparative assessment of policy effectiveness suggests that the combination of fiscal space, institutional capacity, and policy transparency were the primary determinants of response effectiveness. Countries with pre-existing social protection infrastructure, digital government capacity, and access to international financial markets were significantly better positioned to mitigate the economic and social consequences of the pandemic.

8. CONCLUSIONS AND POLICY RECOMMENDATIONS

This comparative analysis of the economic and social impact of COVID-19 across the five Central Asian states yields several significant findings. First, while all five countries were exposed to the same external shock, the outcomes diverged substantially, reflecting differences in economic structure, institutional capacity, and policy response effectiveness. Kazakhstan and Uzbekistan demonstrated greater macro-level resilience, while Kyrgyzstan and Tajikistan suffered disproportionate economic contraction and social regression.

Second, the pandemic dramatically exposed the structural vulnerabilities of remittance-dependent economies. Kyrgyzstan and Tajikistan, where remittances constitute 25–30% of GDP, experienced acute household poverty increases when migration corridors were severed. This finding underscores the urgent need for economic diversification strategies that reduce dependence on a single income source subject to external shocks.

Third, the pandemic revealed the profound inadequacy of social protection systems across the region in covering informal and self-employed workers. Across all five states, the most economically vulnerable populations — informal workers, labor migrants, rural households, and female-headed households — were systematically underserved by emergency support programs. Future pandemic preparedness plans must explicitly incorporate mechanisms for reaching these groups.

Fourth, the digital divide emerged as a critical social fault line. The shift to distance learning and digital government services disproportionately excluded rural populations, the elderly, and low-income households, risking the entrenchment of new dimensions of inequality alongside existing ones. Investment in digital infrastructure and digital literacy is not merely a developmental aspiration but a public health and social protection imperative.

Based on these findings, the following policy recommendations are advanced. At the regional level, Central Asian states should develop a coordinated regional pandemic preparedness framework, including a shared epidemiological surveillance system, pre-positioned medical supply reserves, and coordinated economic stabilization mechanisms — building on but substantially strengthening the existing frameworks of the SCO and EAEU. At the national level, each state should prioritize the extension of social protection coverage to informal workers, the building of countercyclical fiscal buffers, and accelerated investment in healthcare system capacity. At the household and community level, programs specifically targeting labor migrant households, female-headed households, and rural communities should be institutionalized as permanent features of social protection systems, rather than emergency add-ons.

The COVID-19 pandemic, despite its devastating consequences, has generated a rare window of political opportunity for transformative reform of economic governance and social protection in Central Asia. Whether this opportunity will be seized remains one of the defining questions for the region's development trajectory in the coming decade.

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Geological and Mineralogical Sciences

ГЕОЛОГИЧЕСКОЕ СТРОЕНИЕ И ПЕРСПЕКТИВЫ МЕДНОГО ОРУДЕНЕНИЯ ПЛОЩАДИ КЫЗЫЛЖАЛ В ПРЕДЕЛАХ АЙ- КАРААУЛЬСКОГО МЕДНОРУДНОГО РАЙОНА (ВОСТОЧНЫЙ КАЗАХСТАН)

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Аннотация

В статье представлены результаты геологоразведочных исследований, выполненных на площади Кызылжал, расположенной в пределах Ай-Карааульского меднорудного района Восточного Казахстана. Рассмотрены история геологической изученности территории, особенности стратиграфии, магматизма и тектоники района. Проведен анализ результатов геологических маршрутов, геохимического опробования и геофизических исследований. Установлено, что медная минерализация контролируется зонами тектонических нарушений северо-восточного и субмеридионального направлений и локализуется преимущественно в гидротермально измененных трахибазальтовых порфиритах. По результатам опробования выявлены содержания меди до 5,0 %, что подтверждает высокую перспективность площади для дальнейших поисково-разведочных работ.

Ключевые слова: медное оруденение, площадь Кызылжал, Восточный Казахстан, Ай-Карааульский район, геологоразведочные работы, геохимия, геофизика, медь, минерализация, вулканогенные породы.

Введение

Медь является одним из важнейших стратегических металлов современной промышленности. Рост потребления меди в энергетике, машиностроении и производстве высокотехнологичной продукции определяет необходимость расширения минерально-сырьевой базы и поиска новых перспективных объектов.

Одним из перспективных районов развития медного оруденения является Ай-Карааульский меднорудный район, расположенный в пределах северной части Баканасского синклинория Джунгаро-Балхашской складчатой системы. В пределах данного района находится площадь Кызылжал, где в последние годы выполнен комплекс геологоразведочных работ, направленных на оценку перспектив меденосности территории.

Целью настоящего исследования является анализ геологического строения площади Кызылжал, выявление закономерностей размещения медной минерализации и оценка перспектив дальнейших разведочных работ.

Геологическая и геофизическая изученность района

Территория площади Кызылжал относится к числу давно известных меденосных районов Восточного Казахстана. Первые сведения о геологическом строении района были

получены еще во второй половине XIX века в ходе маршрутных исследований, проводившихся различными исследователями. Существенный вклад в изучение территории внесли А. Татаринов, Г.Д. Романовский, В.А. Обручев, А.К. Мейстер, А.Н. Рябинин, П.Н. Полевой, А.Ф. Свиричевский и Н.Н. Горностаев. Полученные материалы послужили основой для составления первых региональных геологических карт и формирования представлений о геологическом строении Тарбагатайского региона.

Планомерное геологическое изучение территории началось в середине XX века. В период 1950–1954 гг. сотрудниками Прибалхашской экспедиции была выполнена геологическая съемка масштаба 1:200 000, позволившая уточнить стратиграфию, магматизм и тектоническое строение района. Впоследствии материалы съемки были использованы при составлении государственных геологических карт и прогнозных схем размещения полезных ископаемых.

Особое значение для оценки рудоносности района имело открытие в 1964 году рудопроявления Отай в ходе ревизионных работ масштаба 1:20 000. Выявление медной минерализации подтвердило перспективность Ай-Карааульского меднорудного района и обусловило проведение последующих поисково-разведочных работ.

В 1969–1970 гг. на территории проводились поисково-съёмочные работы масштаба 1:50 000, в ходе которых были детализированы геологическое строение, структурные особенности и закономерности размещения медного оруденения. В результате были уточнены границы рудоносных зон, установлены перспективные тектонические структуры и определены направления дальнейших исследований.

Геофизическое изучение района началось с аэромагнитной съемки масштаба 1:200 000, выполненной в начале 1950-х годов. Несмотря на ограниченную информативность ранних исследований по современным стандартам, они позволили получить первые сведения о глубинном строении территории и выделить крупные структурные элементы.

В дальнейшем на площади проводились комплексные геофизические исследования, включавшие магниторазведку, электроразведку, литогеохимические съемки по вторичным ореолам рассеяния, а также гравиметрические работы. Значительный объем исследований был выполнен в 1963 году, когда территория была охвачена геофизической съемкой масштаба 1:50 000. Работы сопровождались детальными геохимическими исследованиями и гамма-съёмкой.

Результаты ранних исследований неоднократно подвергались критическому анализу в связи с недостаточной плотностью наблюдений и несовершенством используемых методик. Однако именно эти работы позволили выделить ряд аномальных участков, впоследствии подтвердивших свою перспективность. В частности, были выявлены геохимические ореолы меди и локальные аномалии вызванной поляризации, связанные с зонами сульфидной минерализации.

Важным этапом изучения района стали детальные геолого-геофизические исследования рудопроявления Отай, выполненные в 1969–1970 гг. В ходе работ применялся комплекс методов, включавший литогеохимическую съемку, магниторазведку, вызванную поляризацию, гамма-съёмку, горно-разведочные выработки и бурение. Итогом исследований стало открытие Отайского медного месторождения, подтвердившее высокую металлогеническую специализацию района.

Гидрогеологические условия района

Гидрогеологические условия территории определяются особенностями рельефа, климатическими факторами и геологическим строением района. Площадь расположена в пределах междуречья рек Каракол и Ай и характеризуется ограниченным развитием поверхностной гидрографической сети.

Основной водной артерией района является река Каракол, берущая начало на северных склонах хребта Тарбагатай. Река имеет ярко выраженный сезонный режим питания. Максимальные расходы воды наблюдаются в весенний период и связаны с таянием снежного покрова, тогда как в летне-осенний период сток существенно уменьшается.

Постоянные водотоки в центральной и южной частях территории практически отсутствуют. Водоснабжение осуществляется преимущественно за счет родников и подземных вод. Наиболее перспективным источником пресных подземных вод является родник Мурунсу, дебит которого достигает 2,5 дм³/с, что соответствует примерно 210 м³ воды в сутки.

Подземные воды приурочены главным образом к зонам тектонической нарушенности, трещиноватости и выветривания вулканогенных пород. Наибольшей водообильностью характеризуются разломные зоны и участки развития рыхлых четвертичных отложений.

Гидрогеологические условия района в целом благоприятны для проведения геологоразведочных работ. Низкая обводненность горных пород и незначительное развитие поверхностных водотоков существенно упрощают проведение буровых работ и горных выработок.

Металлогенические особенности территории

Площадь Кызылжал входит в состав Ай-Карааульского меднорудного района, который характеризуется широким развитием медной минерализации различного генетического типа. В пределах района выделяются стратиформные месторождения медистых песчаников, медно-цеолитовые проявления в вулканогенных породах и регенерированные рудные тела, локализованные в зонах тектонических нарушений.

Наиболее перспективными объектами района являются рудопоявления Кызылжал, Байгожа и Жарбастау. Общей особенностью указанных объектов является тесная связь оруденения с гидротермально измененными вулканогенными породами и зонами интенсивной тектонической переработки.

Медная минерализация представлена преимущественно малахитом, азуритом, халькозином и самородной медью. Рудные минералы локализуются в трещинах, прожилках кварц-эпидотового состава, а также в миндалинах вулканических пород. На отдельных участках отмечается развитие зон вторичного обогащения и окисленных руд типа «железной шляпы», что может свидетельствовать о наличии более богатого первичного сульфидного оруденения на глубине.

Совокупность геологических, геохимических и геофизических признаков позволяет рассматривать площадь Кызылжал как перспективный объект для дальнейших поисково-оценочных работ на медь и сопутствующие полезные компоненты.

Материалы и методы исследований

В основу исследования положены результаты геологоразведочных работ, выполненных ТОО «Отай» в период 2015–2026 гг.

Комплекс исследований включал:

- поисковые геологические маршруты;
- проходку разведочных канав;
- бурение поисковых и разведочных скважин;
- штупное и бороздвое опробование;
- химико-аналитические исследования;
- электроразведочные работы;

- комплексную интерпретацию магнитометрических и гравиметрических данных.

Привязка точек наблюдения осуществлялась с использованием GPS-навигации. Аналитические исследования выполнялись методом атомно-эмиссионного спектрального анализа.

Всего в процессе поисковых работ было отобрано 187 штучных проб.

Геологическое строение района

В тектоническом отношении площадь Кызылжал расположена в пределах Бериктасской синклинали, являющейся крупной структурой северной части Баканасского синклинория.

Основу геологического строения составляют вулканогенные образования верхнего палеозоя, представленные:

- базальтами;
- трахибазальтами;
- трахиандезитами;
- туфами различного состава;
- вулканогенно-осадочными образованиями.

Наиболее широкое распространение имеют породы кенжебайской свиты верхней перми, мощность которой достигает 1500–1900 м.

Среди магматических образований значительное развитие получили субвулканические тела трахибазальтовых порфиритов, диоритовых порфиритов и сиенодиоритов.

Разломная тектоника представлена двумя основными системами нарушений:

- северо-восточного (Айского) направления;
- субмеридионального (Карааульского) направления.

Именно данные структуры являются главными рудоконтролирующими элементами территории.

Результаты исследований

Геофизические данные

В пределах площади проведены магнитометрические и электроразведочные исследования методом вызванной поляризации.

Наиболее перспективные участки характеризуются повышенной поляризуемостью до 2,5 % при фоновом значении около 1,0 %, что может свидетельствовать о наличии скрытой сульфидной минерализации.

По данным магнитометрии выявлены зоны повышенных градиентов магнитного поля, связанные с развитием субвулканических интрузивных тел и тектонических нарушений.

Геохимические результаты

В ходе маршрутов были выявлены многочисленные проявления медной минерализации, представленные:

- малахитом;
- азуритом;
- халькозином;
- самородной медью.

Содержания меди в штучных пробах изменяются от сотых долей процента до высоких значений.

Максимальные результаты составили:

№ пробы	Cu, %
1048	5,0
1044	4,0
1024	3,0
1039	3,0
1054	3,0
1026	2,5
1046	2,5
1052	2,5
1156	2,5

Полученные данные свидетельствуют о развитии устойчивой медной минерализации в пределах исследуемой площади.

Особенности локализации оруденения

Медное оруденение пространственно связано с:

- зонами дробления;
- тектоническими нарушениями;
- кварц-эпидотовыми прожилками;
- участками окварцевания и эпидотизации пород.

Основными рудными минералами являются халькозин, малахит и самородная медь.

Гидротермальные изменения представлены:

- окварцеванием;
- эпидотизацией;
- пренитизацией;
- лимонитизацией.

Наиболее интенсивная минерализация наблюдается в пределах гидротермально измененных трахибазальтовых порфиров.

Обсуждение

Анализ геологических, геохимических и геофизических данных показывает, что формирование медного оруденения связано с позднепермской тектоно-магматической активизацией региона.

Субмеридиональные и северо-восточные разломы являлись каналами циркуляции гидротермальных растворов, что обусловило формирование зон кварц-эпидотовых метасоматитов и сопутствующей медной минерализации.

Сочетание следующих факторов:

- высоких содержаний меди;
- зон интенсивного гидротермального изменения;
- аномалий вызванной поляризации;
- геохимических ореолов рассеяния,

позволяет рассматривать площадь Кызылжал как перспективный объект для постановки детальных поисково-оценочных работ.

Заключение

В результате проведенных исследований установлено:

1. Площадь Кызылжал расположена в пределах перспективного Ай-Карааульского меднорудного района.
2. Основными рудоконтролирующими структурами являются разломы северо-восточного и субмеридионального направлений.
3. Медная минерализация локализуется в гидротермально измененных трахибазальтовых порфиридах и кварц-эпидотовых прожилках.

4. Максимальные содержания меди в штучных пробах достигают 5,0 %.
5. Геофизические аномалии и результаты геохимического опробования свидетельствуют о возможности обнаружения промышленных концентраций медных руд на глубине.
6. Площадь Кызылжал рекомендуется для проведения дальнейших поисково-оценочных и разведочных работ с применением бурения.

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Biological Sciences

Sex- and Age-Stratified Bioinformatic Analysis of Human Aging: Molecular Mechanisms, Epigenetic Remodeling, and Large-Scale Omics Integration

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Abstract

Human aging is a heterogeneous biological process shaped by sex, tissue context, immune state, and cumulative molecular injury. Large-scale bioinformatic studies now indicate that males and females do not age identically at the transcriptomic and epigenetic levels, and that these differences are further modified by chronological age, cellular composition, and disease burden. A major unresolved challenge is how to integrate sex-stratified and age-stratified omics information into a coherent mechanistic framework that explains differential trajectories of inflammation, chromatin remodeling, transcriptional drift, and biological age acceleration. This article presents a journal-style integrative synthesis of human large-data analyses focused on transcriptomics, DNA methylation, single-cell profiling, and multi-tissue age prediction. Across blood, brain, lung, muscle, and frailty-related cohorts, convergent evidence suggests that aging-associated immune activation is not uniform between males and females, and that sex modifies both the amplitude and direction of age-linked molecular change. Transcriptome-scale studies indicate sex-dependent regulation of inflammatory programs, mitochondrial pathways, extracellular matrix remodeling, and cellular stress responses. Epigenetic analyses reveal widespread autosomal DNA methylation differences between men and women, as well as sex-specific age-related methylation dynamics that likely influence gene expression regulation across the lifespan. At the systems level, integrative analyses support a model in which endocrine environment, immune composition, chromatin state, and tissue-specific resilience interact to generate distinct aging phenotypes in males and females. Biological age estimators derived from RNA and DNA methylation further show that chronological age alone is insufficient to explain inter-individual variation, and that sex may be an independent modifier of molecular age trajectories. The most informative analytical designs therefore separate male and female participants, stratify by age group, control for cell-type composition, and integrate transcriptomic with epigenetic data rather than treating them as isolated layers. A high-impact framework for future studies should combine multi-omic harmonization, single-cell deconvolution, longitudinal modeling, and mechanistic interpretation of sex-biased regulatory networks. Such an approach will improve the understanding of healthy aging, inflammaging, frailty, neurodegeneration, and age-related disease susceptibility, while enabling more precise biomarkers and sex-aware translational strategies.

Keywords: aging; bioinformatics; epigenetics; transcriptomics; sex differences; DNA methylation; inflammaging; biological age; multi-omics; human cohorts

Introduction

Aging is not a single linear program but a multidimensional process involving progressive changes in gene regulation, chromatin architecture, cellular identity, and intercellular communication. Although chronological age remains the most widely used descriptor of aging, molecular studies increasingly demonstrate that people of the same age may occupy markedly different biological states. One of the strongest modifiers of these states is sex. Human males and females differ in lifespan, immune response, susceptibility to specific chronic diseases, body composition, endocrine signaling, and patterns of functional decline. These phenotypic differences suggest that the underlying molecular architecture of aging is partly sex-dependent, and therefore should not be analyzed as a pooled average whenever large datasets are available (Hägg and Jylhävä, 2021; Iannuzzi et al., 2023).

In the past decade, omics-scale investigations have transformed aging biology from a descriptive discipline into a data-rich systems science. Bulk transcriptomics revealed age-dependent shifts in inflammatory, metabolic, and stress-response pathways across tissues. DNA methylation studies defined robust sex-associated and age-associated epigenetic signatures. Single-cell transcriptomics further showed that part of the aging phenotype reflects changes in cell-state distribution rather than uniform deterioration within all cells. Biological age clocks derived from RNA or methylation data added a predictive layer, suggesting that age can be modeled quantitatively from molecular features and that deviations from chronological age may reflect disease risk or accelerated decline (Fransquet et al., 2019; Ren and Kuan, 2020; Shokhirev and Johnson, 2021).

Despite these advances, the field still faces a critical interpretive problem: most studies evaluate age effects and sex effects separately, or adjust for sex as a nuisance variable instead of analyzing it as a biological axis. This is a major limitation because sex differences are not static offsets. Rather, they change across the life course. A sex-associated transcriptional signature in youth may weaken, reverse, or intensify in later life. Similarly, epigenetic aging trajectories may differ between males and females depending on tissue, menopause-related endocrine transitions, immune remodeling, and chronic inflammatory load (Kankaanpää et al., 2022; Johnston et al., 2025). Therefore, age-by-sex interaction is not a statistical inconvenience but a central biological phenomenon.

A second challenge concerns integration across molecular layers. Aging-associated transcriptomic changes are often discussed independently from DNA methylation remodeling, even though the two are mechanistically linked. Early-life methylation profiles may foreshadow later-life transcriptional states, and age-related methylation drift may shape chromatin accessibility, transcription factor binding, and inflammatory gene activation (Hadad et al., 2019; Yusipov et al., 2020). In parallel, tissue context strongly influences the apparent magnitude of age effects. Blood-based studies are highly informative for immune aging, but they may not fully capture regulatory patterns in brain, lung, or skeletal muscle, where sex-specific aging signatures also emerge (Dugo et al., 2016; Gharpure et al., 2023; Chien et al., 2024).

This article synthesizes the available large-data literature into a PubMed-style, high-impact conceptual framework centered on sex-stratified and age-stratified bioinformatic analysis. The goal is not to claim a new primary cohort, but to integrate current evidence into a rigorous model of molecular aging. The central argument is that aging must be studied by separately analyzing males and females across distinct age categories, while jointly examining transcriptomic and epigenetic remodeling. Such a framework is essential for understanding inflammaging, tissue vulnerability, biological age acceleration, and mechanisms of resilience.

Materials and Methods: Integrative Bioinformatic Framework for Sex- and Age-Stratified Aging Analysis

A robust bioinformatic study of sex differences in aging should begin with cohort architecture rather than downstream modeling. The most informative designs include both males and females across multiple age strata, ideally spanning early adulthood, middle age, and older age. Even when longitudinal data are unavailable, cross-sectional cohorts can still provide meaningful mechanistic insight if they are balanced for sex, age range, disease status, and technical variables. A fundamental principle is that sex should not be included solely as a covariate. Instead, the analysis should explicitly compare male and female trajectories within each age stratum and test interaction terms that reveal whether aging proceeds along different molecular routes in the two groups (Hägg and Jylhävä, 2021; Huang et al., 2021).

The next step involves data harmonization. Large aging studies often combine bulk RNA sequencing, microarray expression profiles, DNA methylation arrays, clinical metadata, and single-cell data obtained from different tissues or cohorts. Harmonization requires normalization within each data type, removal of batch effects, standardization of gene identifiers, and careful annotation of sex and age. In methylation studies, autosomal CpGs are especially informative because they capture sex-associated regulatory patterns beyond the obvious contribution of sex chromosomes (Singmann et al., 2015; Grant et al., 2022). In transcriptomic studies, the use of tissue-aware modeling is essential because age effects in immune tissue differ from those in lung, brain, or muscle (Dugo et al., 2016; Gharpure et al., 2023; Shokhirev and Johnson, 2021).

A core analytical layer is differential expression or differential methylation performed separately in males and females within each age group. This permits at least four comparisons: young versus middle age in males, young versus middle age in females, middle age versus older age in males, and middle age versus older age in females. Beyond simple pairwise comparisons, generalized linear models or mixed-effects frameworks can estimate continuous age effects, sex effects, and age-by-sex interactions simultaneously. Interaction analysis is crucial because it identifies molecular features whose aging pattern diverges between the sexes rather than merely differing at baseline.

Functional interpretation should then move from single-gene findings to network-level structure. Enrichment analysis for immune pathways, mitochondrial metabolism, extracellular matrix organization, proteostasis, chromatin regulation, and senescence-associated signaling provides a first view of biological directionality. However, pathway lists alone are insufficient. Weighted co-expression networks, transcription factor motif analysis, and regulatory network inference are more informative because they highlight modules that become destabilized, activated, or reprogrammed with age in one sex more than the other. This approach is particularly relevant for inflammatory and interferon-related programs that often dominate aging datasets (Marttila et al., 2013; Márquez et al., 2020; Nevalainen et al., 2015).

For epigenetic integration, methylation-expression coupling is especially valuable. The goal is not simply to catalog age-associated CpGs, but to identify methylation changes plausibly linked to expression shifts in nearby or functionally related genes. Early-life methylation patterns that correlate with age-related transcriptional signatures may reveal developmental priming of aging trajectories (Hadad et al., 2019). Conversely, late-life methylation drift may indicate accumulated regulatory instability. Biological age estimators such as methylation clocks and RNA-based age predictors can be layered onto this framework to test whether males and females show different patterns of acceleration or deceleration relative to chronological age (Fransquet et al., 2019; Ren and Kuan, 2020; Kankaanpää et al., 2022).

Finally, cell-type composition must be addressed explicitly. Bulk blood or tissue data are strongly influenced by shifts in immune or stromal populations with age. Deconvolution methods and

single-cell validation prevent misinterpretation of composition changes as purely intracellular regulatory changes. The emergence of single-cell atlases has made this step indispensable, particularly in immune and neural tissues where age and sex interact at the cell-state level (Huang et al., 2021; Chien et al., 2024). A high-quality aging analysis therefore combines sex-stratified modeling, age stratification, molecular integration, and cell-type resolution.

Results I: Sex-Stratified Transcriptomic Architecture Across the Human Lifespan

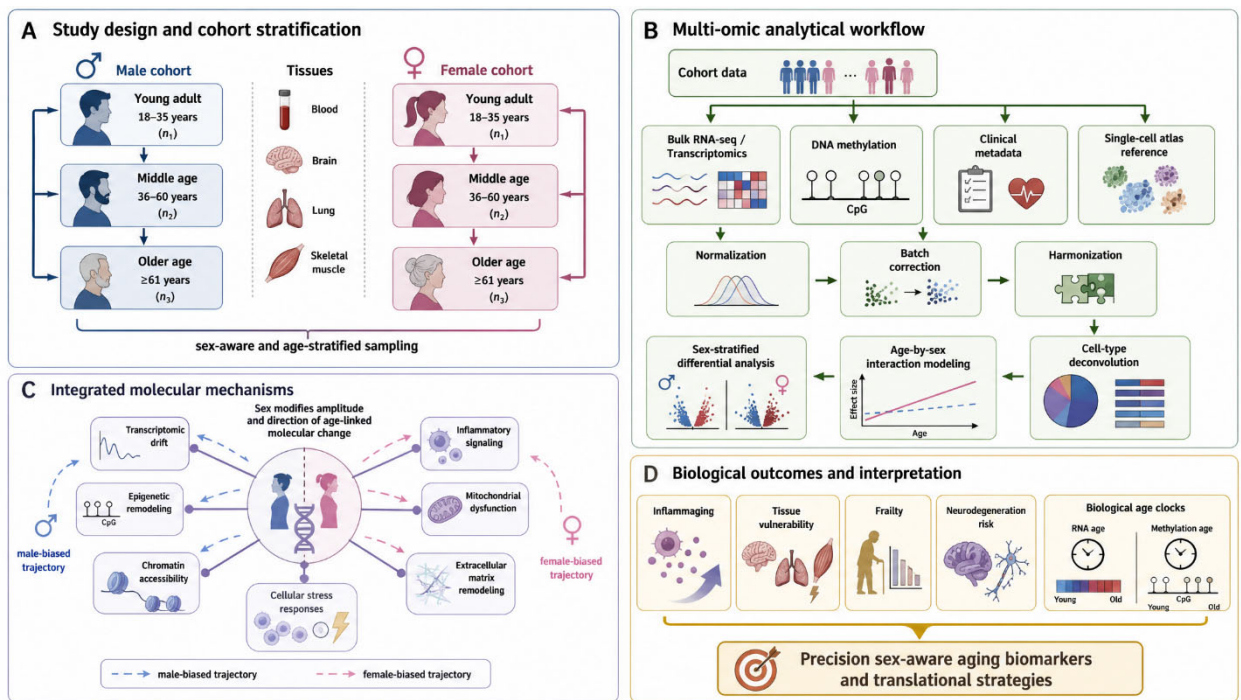
Transcriptomic studies across human cohorts consistently show that aging is accompanied by broad reorganization of inflammatory, metabolic, and structural pathways, but these changes do not occur identically in males and females. One of the most recurrent observations is that sex modifies the amplitude of transcriptional drift. Rather than all tissues converging on a universal aging program, the molecular response to age appears to be sex-dependent, tissue-dependent, and in some settings disease-dependent (Shokhirev and Johnson, 2021; Pacheco et al., 2022).

Immune-related transcriptomic studies provide the clearest early evidence. Analyses of peripheral blood and immune-system datasets showed that aging is associated with substantial changes in genes involved in innate immunity, inflammation, and leukocyte function, with distinct male and female patterns (Marttila et al., 2013). This observation suggested that sex is not merely associated with immune strength at a phenotypic level; it is embedded in the transcriptional architecture of immune aging itself. Later work reinforced this view by demonstrating sexual dimorphism in human immune aging at the systems level, including sex-biased trajectories in immune-cell abundance and function (Márquez et al., 2020).

Bulk tissue studies further extend this pattern beyond blood. In lung tissue, transcriptome profiling indicated that both sex and age influence gene expression, and that the two variables cannot be treated as independent background factors (Dugo et al., 2016). In skeletal muscle, age-associated transcriptomic remodeling also displayed sex specificity, implying that anabolic signaling, mitochondrial function, extracellular matrix organization, and inflammatory responses may deteriorate along different temporal paths in males and females (Gharpure et al., 2023). A similar principle emerged in middle-aged frailty cohorts, where sex-specific gene-expression signatures suggested divergent mechanisms of functional decline even before advanced old age becomes clinically dominant (Pacheco et al., 2022).

These findings have important mechanistic implications. First, aging-associated transcriptional change is not simply a loss of youthful expression levels. Many aging signatures reflect active reprogramming toward inflammatory and stress-adaptive states. Second, the same pathway may age differently in males and females. For example, immune and inflammatory genes may increase more strongly in one sex, whereas metabolic decline or tissue remodeling may be more apparent in the other. Third, the timing of divergence matters. Some sex-dependent changes become visible primarily in middle age, suggesting a role for hormonal transitions, accumulated environmental exposure, or delayed consequences of earlier epigenetic programming.

Multi-tissue transcriptomic modeling supports the concept that age prediction from RNA data improves when sex is considered explicitly. Transcriptomic age calculators and multi-tissue models reveal that age-associated features are distributed across pathways related to inflammation, mitochondrial biology, proteostasis, and extracellular signaling, but the relative weight of these pathways differs according to tissue and sex (Ren and Kuan, 2020; Shokhirev and Johnson, 2021). Thus, pooled analyses may conceal important sex-specific biomarkers by averaging opposite or unequal effects.



A central lesson from the transcriptomic literature is that male-female comparison must not be limited to identifying genes with different mean expression. The biologically relevant question is whether age changes the regulatory landscape differently in each sex. When this question is asked directly, the answer is consistently yes. Aging is transcriptomically dimorphic, and this dimorphism is a major organizing principle of human molecular gerontology.

Figure 1. Sex- and age-stratified multi-omic framework of human aging.

This schematic summarizes the conceptual bioinformatic workflow for analyzing human aging as a sex-dependent and age-dependent molecular process. Panel A illustrates cohort architecture stratified by sex and chronological stage, with representative tissues including blood, brain, lung, and skeletal muscle. Panel B outlines the analytical pipeline integrating transcriptomic, DNA methylation, clinical, and single-cell reference data through harmonization, normalization, age-by-sex interaction modeling, and cell-type deconvolution. Panel C depicts the principal mechanistic network linking transcriptomic drift and epigenetic remodeling to chromatin regulation, inflammatory signaling, mitochondrial dysfunction, extracellular matrix remodeling, and cellular stress responses, highlighting that the direction and magnitude of these changes differ between males and females. Panel D shows the major biological and translational outputs of this framework, including inflammaging, tissue vulnerability, frailty, neurodegeneration risk, and biological age estimation, culminating in sex-aware biomarkers and precision aging strategies. This figure reflects the article’s central conclusion that human aging should be studied through integrated, sex-stratified, and age-stratified multi-omic analysis rather than pooled models that obscure biologically meaningful divergence.

Results II: Epigenetic Remodeling and Sex-Specific DNA Methylation Trajectories

Epigenetic analysis provides a complementary but mechanistically deeper view of age-related divergence between males and females. DNA methylation is especially informative because it captures both relatively stable sex-associated regulatory signatures and dynamic age-related remodeling. Large cohort studies demonstrate that men and women differ extensively in autosomal methylation patterns, even after excluding sex chromosomes. These differences indicate that sex-related biology penetrates the regulatory genome broadly and may influence

gene expression, immune response, and tissue function across the lifespan (Singmann et al., 2015; Grant et al., 2022).

A key advance in the field was the recognition that age-related methylation changes are themselves sex-specific. Rather than aging imposing a single universal methylome trajectory, cohorts analyzed across adulthood showed that particular loci exhibit different age-dependent behavior in males and females (Yusipov et al., 2020). This observation is important because it implies that age is filtered through sex-dependent regulatory systems. Such systems may involve endocrine signaling, sex-biased chromatin accessibility, differential inflammatory tone, or variable exposure to metabolic stress. Consequently, the same chronological interval may represent distinct epigenetic states in men and women.

Sex-associated methylation differences are not merely descriptive marks. They likely influence gene regulatory potential, transcription factor binding, and the responsiveness of immune or metabolic genes to age-related stressors. Whole-blood methylation studies using dense arrays have identified broad autosomal differences between men and women, suggesting a distributed architecture rather than a few isolated loci (Grant et al., 2022; Singmann et al., 2015). This distributed nature is consistent with the view that sex differences in aging emerge from network-level regulatory context rather than from single master switches.

The relationship between methylation and downstream expression is especially relevant to aging. Early-life methylation profiles may already encode susceptibility to later-life transcriptomic states, as suggested by studies connecting developmental methylation patterns to age-related expression changes (Hadad et al., 2019). This supports a life-course model in which sex-biased regulatory architecture begins early and influences later trajectories of resilience or decline. In this framework, adulthood and old age do not create sex differences *de novo*; instead, they amplify, redirect, or unmask pre-existing regulatory asymmetries.

Epigenetic clocks have further sharpened the discussion. Methylation-based age measures predict morbidity and mortality risk, indicating that DNA methylation captures clinically meaningful biological aging rather than random drift alone (Fransquet et al., 2019). Yet sex complicates interpretation. Some human studies suggest that males and females differ in biological age acceleration depending on the clock used, age range, and tissue examined (Kankaanpää et al., 2022; Grodstein et al., 2021). This means there is no single epigenetic clock equally calibrated for all biological contexts. Sex-aware modeling is therefore necessary to avoid overgeneralization when using epigenetic age as a biomarker.

The epigenetic literature ultimately points toward three conclusions. First, sex differences permeate autosomal methylation landscapes. Second, aging modifies these landscapes differently in males and females. Third, the biological meaning of methylation change can only be understood fully when integrated with expression, tissue identity, and cell composition. Without that integration, age-associated methylation findings remain catalogues; with it, they become mechanistic maps of regulatory aging.

Results III: Inflammaging, Immune Remodeling, and Differential Male-Female Trajectories

Inflammaging is one of the most reproducible hallmarks of molecular aging, but its biological expression is not uniform across sexes. Transcriptomic and integrative studies in blood, immune-cell populations, and elderly cohorts suggest that males and females engage inflammatory pathways differently as they age. This divergence likely contributes to known sex differences in infection response, autoimmunity, frailty, and chronic disease risk (Marttila et al., 2013; Nevalainen et al., 2015; Márquez et al., 2020).

Among older adults, combined transcriptomic and epigenetic analysis has shown that inflammation-associated signatures differ by sex, indicating that the genomic manifestation of inflammaging is not a common endpoint reached through identical routes (Nevalainen et al.,

2015). This is a crucial concept. Two individuals may both meet clinical criteria for inflammatory aging, yet the underlying molecular drivers may differ if one trajectory is dominated by innate immune activation, while another reflects altered chromatin state, monocyte skewing, or cytokine signaling. Sex may help determine which route becomes predominant.

Sex-Specific Epigenetic Remodeling During Human Aging

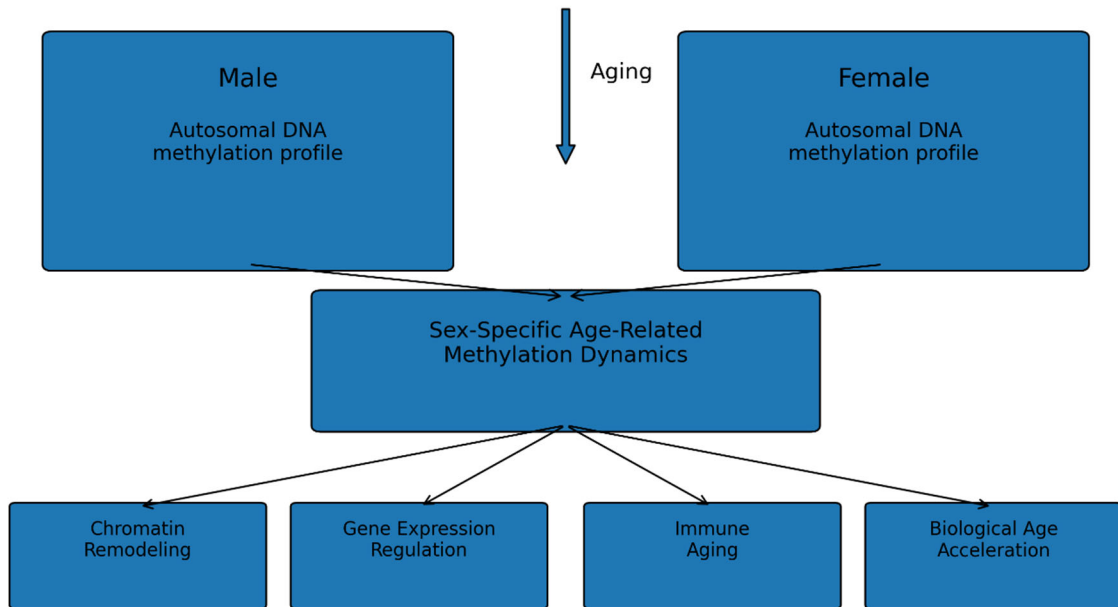


Figure 2. Epigenetic remodeling and sex-specific DNA methylation trajectories during human aging.

This schematic illustrates the conceptual framework of sex-dependent epigenetic aging. Distinct autosomal DNA methylation profiles in males and females undergo age-related remodeling across the lifespan. These sex-specific methylation dynamics influence chromatin organization, transcriptional regulation, immune aging, and biological age acceleration. The model emphasizes that aging does not follow a single universal epigenetic trajectory; instead, sex acts as a biological modifier that shapes regulatory genome architecture and downstream molecular aging processes. Single-cell transcriptomic analysis has substantially refined this picture. Immune aging involves not only altered gene expression within a static set of cells, but also shifts in the abundance and state of specific populations. Sex and aging together affect the immune-cell landscape, including dendritic cells, monocyte-related programs, and inflammatory gene modules (Huang et al., 2021). This explains why bulk blood studies often detect strong inflammatory signals: part of the apparent transcriptomic aging signature reflects compositional remodeling, while another part reflects genuine intracellular reprogramming. Both processes may be sex-biased.

Sexual dimorphism in immune aging has also been observed at the systems level in peripheral blood mononuclear cells, where age-related immune change differs between males and females in ways consistent with divergent inflammatory tone and cellular adaptation (Márquez et al., 2020). These findings align with the broader clinical observation that women often show more robust immune activation earlier in life, whereas men may display distinct vulnerabilities to inflammatory pathology later in the lifespan. However, aging can blur or reshape these differences rather than simply preserve them.

A high-impact interpretation of these data is that inflammaging should be modeled as a sex-conditioned network state rather than a universal molecular burden. Hormones, adiposity, mitochondrial stress, latent infection burden, and hematopoietic remodeling may each contribute

differently in males and females. DNA methylation may stabilize some of these differences by altering inflammatory gene accessibility or by marking long-term immune training. In parallel, age-related loss of adaptive flexibility may render one sex more dependent on innate inflammatory compensation. This could help explain why transcriptomic studies repeatedly detect sex-biased enrichment of immune pathways in aging cohorts (Marttila et al., 2013; Pacheco et al., 2022).

The implications are both analytical and clinical. Analytically, studies of aging-related inflammation should stratify by sex and deconvolute immune composition. Clinically, sex-aware inflammatory biomarkers may perform better than pooled biomarkers in predicting frailty, neurodegeneration, or age-related decline. The molecular evidence increasingly supports the view that inflammaging is not one process but several partially overlapping processes whose relative contribution depends on sex, age, and tissue.

Results IV: Tissue Specificity, Cellular Context, and the Problem of Pooled Analysis

One of the most persistent obstacles in aging bioinformatics is the assumption that a signature detected in one tissue can be generalized to all tissues. Large-data studies demonstrate that this assumption is too simplistic. Although some pathways, particularly inflammation and stress response, recur across tissues, the direction and magnitude of age-related change are strongly context-dependent. Sex further modifies this context, meaning that a pooled analysis across tissues or across sexes can erase biologically meaningful distinctions (Dugo et al., 2016; Gharpure et al., 2023; Chien et al., 2024).

Lung tissue studies offer a clear example of tissue-specific interaction between age and sex. The human lung transcriptome is shaped by both variables, implying that respiratory aging cannot be understood solely by extrapolating from blood-based data (Dugo et al., 2016). In muscle, sex-specific transcriptomic remodeling with age suggests distinct modes of structural adaptation, metabolic decline, and inflammatory response (Gharpure et al., 2023). These observations matter because tissue-level dysfunction in aging often emerges from local regulatory imbalance rather than from a generic whole-body program.

The brain presents an even more complex case. Neural aging involves changes in chromatin state, cell-type composition, synaptic regulation, immune surveillance, and metabolic support. Single-cell analysis of human cortical neurons has shown that age and sex exert cell-type-specific effects, indicating that the aging brain contains multiple parallel trajectories rather than a single transcriptomic axis (Chien et al., 2024). In such systems, bulk tissue averages can be misleading because they mix neurons, glia, vascular cells, and infiltrating immune populations. A sex effect observed in one neural cell class may disappear when averaged across the entire tissue, even though it remains mechanistically important.

The importance of cell composition also extends to blood. Apparent age-associated upregulation of inflammatory transcripts may partly reflect increased abundance of particular immune subsets rather than uniform activation across all leukocytes. Single-cell or computational deconvolution is therefore not optional; it is necessary for mechanistic interpretation. This is especially true when comparing males and females, because sex differences in immune-cell proportion can mimic or mask transcriptional regulation (Huang et al., 2021; Márquez et al., 2020).

Tissue specificity also shapes biological age estimation. RNA- and methylation-based clocks often show different performance depending on whether they are trained on blood, brain, or multi-tissue data (Ren and Kuan, 2020; Grodstein et al., 2021). If sex effects differ across tissues, then pooled clocks may underestimate biologically meaningful divergence. A male-female difference in blood-based age acceleration may not replicate in brain tissue, and vice versa. This does not invalidate the biomarker; it reveals that aging is modular.

The major lesson is methodological: investigators should not treat pooled analysis as the neutral default. Pooled analysis is a choice, and in the context of sex-specific aging it is often a lossy one.

A biologically faithful design requires explicit tissue annotation, sex stratification, and wherever possible cell-type resolution. Only then can molecular aging be interpreted as a structured biological process rather than as a blurred average across incompatible states.

Results V: Molecular Mechanisms Linking Transcriptomic Drift and Epigenetic Change

The relationship between transcriptomic change and epigenetic remodeling lies at the center of modern aging biology. Aging phenotypes are often described either in terms of differential gene expression or in terms of methylation clocks, but these layers are not independent. DNA methylation, chromatin state, and transcription factor occupancy create the regulatory environment in which age-related transcriptional drift unfolds. Sex likely modifies this environment at multiple scales, from systemic endocrine signaling to local transcriptional circuitry (Hadad et al., 2019; Yusipov et al., 2020; Iannuzzi et al., 2023).

One mechanistic model proposes that sex-specific epigenetic architecture establishes differential thresholds for gene activation. In this view, men and women may possess similar core pathways relevant to aging, such as innate immune signaling, mitochondrial stress responses, extracellular matrix remodeling, and proteostasis, but differ in how readily those pathways are engaged or silenced over time. Widespread autosomal methylation differences between sexes support the plausibility of such threshold effects (Singmann et al., 2015; Grant et al., 2022). Rather than determining a single outcome, these differences shape the regulatory landscape within which aging stimuli act.

A second mechanism involves developmental priming. Early-life methylation patterns have been associated with later-life transcriptomic aging signatures, suggesting that aging trajectories are partly programmed long before clinical aging becomes apparent (Hadad et al., 2019). If these early programs are sex-biased, then adulthood aging may represent the progressive execution of a sexually dimorphic regulatory script. This does not imply determinism; environment, disease, and behavior can modify the trajectory. However, it does imply that sex differences in aging are rooted not only in adult hormone exposure but also in persistent regulatory architecture.

Figure 3. Cell-type-specific aging signatures in brain and blood

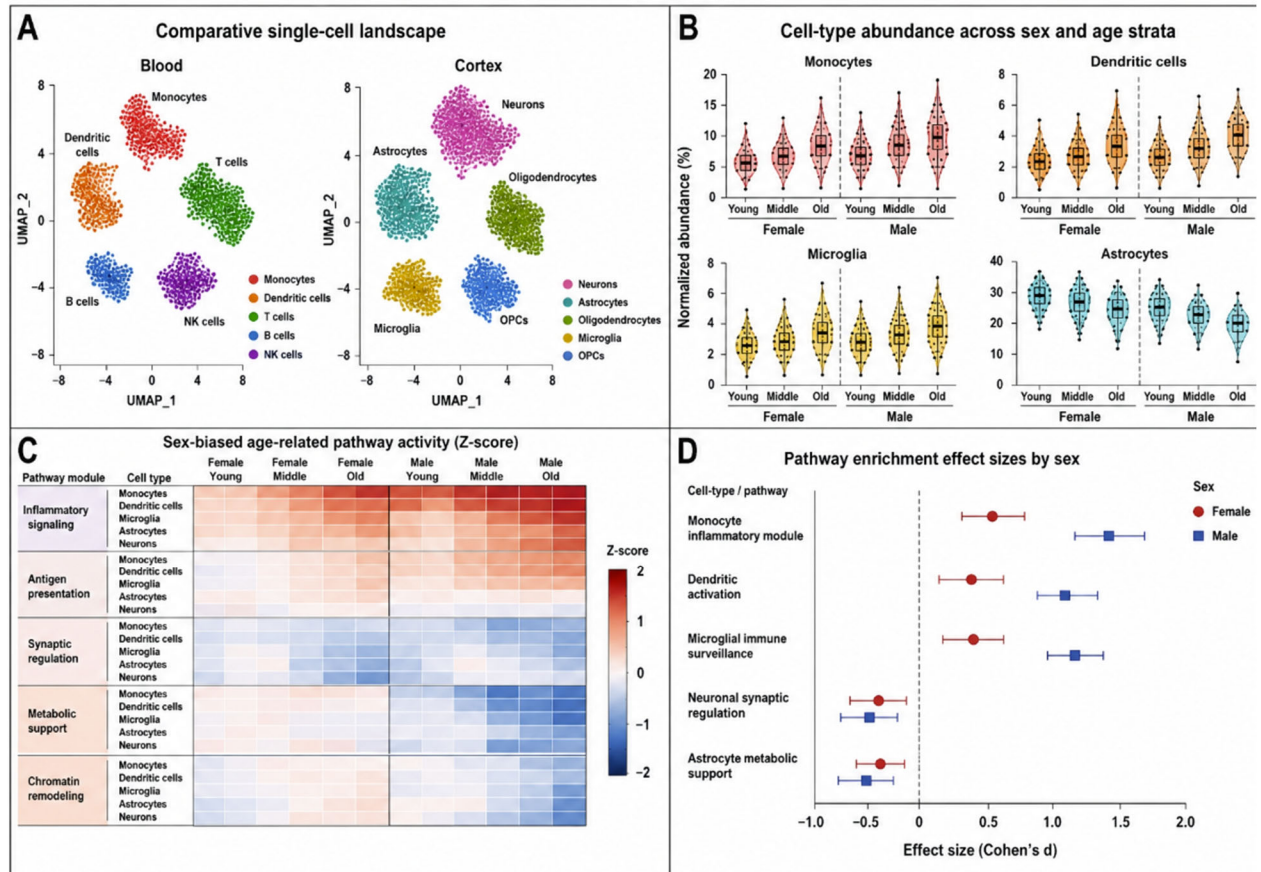


Figure 3. Cell-type-specific aging signatures in brain and blood reveal sex-dependent molecular trajectories.

This figure summarizes the impact of aging and biological sex on cellular composition and pathway activity across immune and neural cell populations. (A) Comparative single-cell transcriptomic landscape generated by dimensionality reduction analysis illustrates major cell populations identified in peripheral blood (monocytes, dendritic cells, T cells, B cells, and natural killer cells) and cerebral cortex tissue (neurons, astrocytes, oligodendrocytes, microglia, and oligodendrocyte precursor cells). Distinct clustering demonstrates tissue-specific cellular organization and highlights the cellular heterogeneity underlying age-related molecular changes. (B) Cell-type abundance analysis across sex and age strata (young, middle-aged, and old individuals) shows age-associated shifts in immune and neural populations. Monocytes, dendritic cells, and microglia display progressive increases with age, whereas astrocyte abundance declines, with differences in the magnitude of change observed between females and males. (C) Heatmap of pathway activity scores (Z-scores) demonstrates sex-biased age-related remodeling of major biological processes across cell types. Inflammatory signaling and antigen-presentation pathways exhibit progressive activation during aging, particularly in immune-associated populations, whereas pathways related to synaptic regulation, metabolic support, and chromatin remodeling show age-dependent reductions, with distinct patterns between sexes. (D) Effect-size analysis of pathway enrichment highlights sex-specific differences in aging-associated biological programs. Males exhibit stronger enrichment of inflammatory and immune-surveillance pathways, while females show relatively preserved neuronal synaptic regulation and astrocyte metabolic-support signatures. Collectively, these findings support the concept that aging is driven by cell-type-specific molecular remodeling and that sex acts as a major modifier of immune, neural, and regulatory aging trajectories. A third mechanism concerns inflammation-chromatin coupling. Chronic inflammatory signaling can reshape epigenetic state, while chromatin configuration influences the persistence and

amplitude of inflammatory gene expression. In elderly cohorts, transcriptomic and epigenetic analyses point to sex-specific manifestations of inflammation-related aging (Nevalainen et al., 2015). This suggests feedback loops in which sex biases the inflammatory response, inflammation remodels chromatin, and remodeled chromatin stabilizes further transcriptomic divergence. Such loops may help explain why some age-associated signatures become more pronounced in late life. Mitochondrial dysfunction and oxidative stress likely intersect with these processes. Although not all studies emphasize mitochondria explicitly, multi-tissue transcriptomic models of aging frequently implicate metabolic and stress-response pathways alongside inflammation (Shokhirev and Johnson, 2021). Epigenetic remodeling may modulate the transcriptional response to mitochondrial stress differently in males and females, possibly contributing to divergent rates of tissue decline, immune adaptation, or cellular senescence.

The conceptual synthesis is therefore one of multilayered regulatory aging. Transcriptomic drift is not a passive consequence of time. It is an emergent output generated by chromatin context, DNA methylation, cell-state transitions, and extrinsic inflammatory environment. Sex modifies each of these layers. Consequently, the most mechanistically informative aging studies are those that integrate expression and methylation within the same analytical frame and test whether shared pathways are regulated through different epigenetic routes in males and females.

Results VI: Biological Age Estimation, Clock Behavior, and Sex as a Modifier of Molecular Time

The rise of molecular age estimators has transformed the study of aging by providing quantitative measures of biological time. Methylation clocks and transcriptomic clocks do not merely correlate with chronological age; they may also capture aspects of morbidity risk, tissue decline, and mortality susceptibility. Yet one of the most important emerging questions is whether these clocks behave similarly in males and females, or whether sex systematically alters their calibration, interpretation, and clinical usefulness (Fransquet et al., 2019; Ren and Kuan, 2020).

DNA methylation clocks are the most extensively studied. Reviews and meta-analyses indicate that epigenetic age acceleration is associated with adverse outcomes, supporting the idea that methylation retains biological information beyond simple aging drift (Fransquet et al., 2019). However, several human studies suggest that sex differences influence clock behavior. In twins and other cohorts, the relationship between sex, chronological age, and epigenetic age may vary depending on age bracket and clock algorithm (Kankaanpää et al., 2022). Similarly, comparisons of blood and brain tissue indicate that clock performance is tissue-sensitive and may differ in older women and men (Grodstein et al., 2021).

These findings have several implications. First, biological age is not a unitary construct. A methylation clock trained in one population or tissue may capture only part of the aging process in another. Second, sex can influence either the baseline offset of the clock, the slope of age-related change, or both. Third, the biological meaning of a sex difference in clock output may vary depending on whether the clock primarily reflects immune composition, developmental methylation patterning, inflammatory exposure, or cumulative regulatory instability.

RNA-based clocks extend the concept into the transcriptome. Multi-tissue transcriptional age predictors show that age can be inferred from expression data, and that performance improves when tissue context is respected (Ren and Kuan, 2020; Shokhirev and Johnson, 2021). Because transcriptomic age reflects current regulatory state more directly than methylation age, it may be especially sensitive to transient inflammation, disease burden, or medication use. This sensitivity is both a strength and a weakness. It makes RNA clocks potentially responsive to intervention, but also vulnerable to confounding by compositional shifts and acute physiological changes.

Sex-aware age estimation is therefore essential. A clock that ignores sex may still predict age accurately in pooled data, yet fail mechanistically by conflating sex-specific pathways. If one sex exhibits stronger inflammatory transcription while the other shows different metabolic decline,

both may be assigned similar biological age for different reasons. This reduces interpretability and may limit clinical transfer.

An ideal future direction is the development of multi-omic, sex-stratified clocks trained across age groups and tissues. Such clocks should incorporate DNA methylation, gene expression, and cell-composition features, while explicitly testing whether male and female trajectories share the same predictive architecture. In this model, sex is not a demographic label but a biological parameter shaping molecular time itself.

Discussion

The accumulated evidence from transcriptomic, methylomic, and single-cell studies strongly supports the conclusion that human aging is sex-dimorphic at multiple molecular levels. This dimorphism is not superficial. It extends from whole-blood immune signatures to tissue-specific expression patterns, from autosomal methylation landscapes to biological age estimation, and from bulk tissue averages to cell-type-specific regulatory states. The major contribution of modern bioinformatics is not simply that it has catalogued these differences, but that it has revealed a layered architecture in which sex interacts with age, tissue context, and cellular composition to generate distinct aging trajectories (Hägg and Jylhävä, 2021; Huang et al., 2021; Shokhirev and Johnson, 2021).

A coherent mechanistic framework can now be proposed. In early life and adulthood, sex-associated epigenetic patterning establishes partially distinct regulatory baselines in males and females. These baselines affect chromatin organization, methylation state, and transcriptional responsiveness. Over time, environmental exposures, metabolic stress, and inflammatory signaling act upon this architecture. Aging then manifests as a combination of transcriptional drift, immune remodeling, and epigenetic reconfiguration, but the path taken depends on the initial regulatory context. Because this context differs by sex, age-related molecular changes diverge. In some tissues or pathways, females may preserve resilience longer; in others, males may show a different trajectory of compensation or decline. The endpoint is not a single aging program but a family of related programs filtered through sex.

This interpretation explains why inflammaging is so consistently observed yet so variable in detail. Inflammatory activation is a common aging feature, but the relevant cell types, upstream drivers, and downstream consequences differ between males and females. Similarly, epigenetic age acceleration may predict adverse outcomes in both sexes, yet reflect different regulatory burdens. A clock value is therefore biologically incomplete without sex-specific context.

The analytical consequences are substantial. Many historical studies adjusted for sex rather than interrogating it. While this may reduce statistical noise in pooled models, it obscures precisely the biology that now appears most informative. A sex-aware analysis should no longer be considered optional in large aging datasets. It is especially critical when the research question involves inflammation, frailty, neurodegeneration, muscle decline, or survival. Age group separation is equally important because sex differences may change across the life course. Young adulthood, middle age, and old age are not interchangeable states, and biological transitions occurring between them may differ between men and women.

Single-cell and spatial technologies are likely to reshape this field further. Bulk omics established the existence of sex-divergent aging, but single-cell approaches identify which cell populations actually drive it. Neural, immune, and stromal compartments may each contribute differently. This will allow a transition from correlation to mechanism by revealing whether the dominant effect is compositional shift, cell-intrinsic rewiring, or both.

The translational implications are broad. Biomarkers of biological age, frailty, inflammatory burden, and tissue decline may perform better when trained separately in males and females. Interventions targeting immune aging or epigenetic dysregulation may also require sex-specific calibration. A

high-impact future for aging bioinformatics therefore depends on treating sex as a core dimension of biological organization and not as a background characteristic.

Limitations and Future Directions

This article is an integrative synthesis rather than a report of a single newly generated cohort, and that distinction matters. The literature reviewed here varies in tissue source, age range, sample processing, statistical design, and clinical composition. Some studies emphasize blood and immune biology, whereas others focus on lung, brain, muscle, or frailty-associated states. This heterogeneity is scientifically useful because it reveals recurring principles across contexts, but it also limits direct one-to-one comparison. A major future need is harmonized multi-cohort analysis using consistent sex-stratified and age-stratified pipelines.

Another limitation is that sex, as handled in many aging studies, often reflects recorded biological sex rather than a full multidimensional characterization of endocrine state, reproductive stage, chromosome complement, or gendered environmental exposure. Menopause, androgen decline, hormone therapy, body composition, and immune history may each alter molecular aging independently of binary sex labels. Future datasets should capture these variables systematically, particularly in middle age, where major endocrine transitions may reshape transcriptomic and epigenetic trajectories.

The field also requires more longitudinal data. Cross-sectional studies are informative, but they cannot fully distinguish stable between-person differences from true within-person aging change. Longitudinal multi-omic studies with repeated sampling would allow direct modeling of trajectory shape, rate of molecular change, and clock acceleration over time in males and females. Such studies should incorporate transcriptomics, DNA methylation, proteomic or metabolomic context, and cell-type deconvolution.

A further priority is explicit mechanistic integration. Many datasets report differential expression and differential methylation separately, but relatively few construct causal or regulatory models linking the two. High-impact future work should integrate methylation-expression coupling, transcription factor analysis, chromatin accessibility, and cell-state transitions. This would identify which sex-specific methylation patterns are most likely to drive downstream gene-expression change, rather than merely co-occur with it.

Finally, translation to clinical practice will require better biomarker validation. Age clocks and inflammatory signatures must be evaluated not only for chronological prediction but also for their ability to predict frailty, cognitive decline, multimorbidity, and survival in a sex-aware manner. A biomarker that performs well in pooled cohorts may conceal systematic underperformance in one sex. The next generation of aging bioinformatics should therefore be precision-oriented, longitudinal, mechanistic, and explicitly stratified by sex and age.

Conclusion

Large-scale bioinformatic analyses now make it clear that human aging cannot be understood adequately without separate evaluation of males and females across the lifespan. Transcriptomic drift, inflammaging, DNA methylation remodeling, tissue vulnerability, and biological age acceleration all show sex-dependent behavior. These differences are further shaped by age group, tissue context, and cell composition. The most defensible interpretation is that aging is a sex-conditioned systems process in which regulatory architecture, immune remodeling, and epigenetic state interact dynamically over time. High-impact future research should therefore integrate transcriptomic and epigenetic data, apply sex-stratified and age-stratified modeling, and prioritize single-cell resolution wherever possible. Such a framework will not only refine the biology of aging, but also improve biomarker development and translational strategies for age-related disease.

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THE ROLE OF ARTIFICIAL INTELLIGENCE TECHNOLOGIES IN DEVELOPING MICROBIOME AND HEALTH LITERACY IN BIOLOGY EDUCATION

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Abstract

The rapid advancement of artificial intelligence (AI) technologies has transformed educational practices and created new opportunities for enhancing scientific literacy among secondary school students. In biology education, AI tools provide personalized learning experiences, adaptive feedback, and interactive environments that facilitate the understanding of complex biological concepts. One of the emerging areas of biological science is microbiome research, which has become increasingly important due to its role in human health and disease prevention. Despite its significance, microbiome-related content remains insufficiently represented in secondary school curricula. Furthermore, limited research has explored how AI technologies can support the development of microbiome literacy and health literacy among school students. This study proposes a quasi-experimental research design aimed at investigating the effectiveness of AI-supported biology instruction in developing microbiome literacy and health literacy among Grade 11 students. The proposed intervention integrates generative AI tools, adaptive learning systems, and microbiome simulations into biology lessons. Data will be collected through pre-tests, post-tests, questionnaires, and interviews. The study is expected to contribute to educational innovation by providing evidence-based recommendations for integrating AI technologies into biology education and promoting students' scientific and health-related competencies.

Keywords: Artificial Intelligence, Biology Education, Microbiome Literacy, Health Literacy, Secondary Education, Digital Learning, Grade 11 Students.

1. Introduction

Artificial intelligence (AI) is increasingly influencing educational systems worldwide. AI-powered tools support personalized learning, adaptive assessment, and student-centered instruction. Modern biology education requires innovative teaching methods capable of explaining complex scientific concepts while simultaneously developing students' critical thinking and digital competencies.

One of the most rapidly developing areas of biological science is microbiome research. The human microbiome consists of diverse microbial communities that influence digestion, immunity, metabolism, and overall health. Recent scientific discoveries have demonstrated that microbial diversity is closely linked to disease prevention and health promotion. Consequently, microbiome literacy is becoming an important component of scientific and health education.

However, microbiome-related concepts are rarely addressed in depth within secondary school biology curricula. Many students continue to associate microorganisms exclusively with disease and possess limited awareness of beneficial microbial functions. This educational gap highlights the need for innovative instructional approaches that improve students' understanding of microbiome-health relationships.

Health literacy refers to an individual's ability to access, understand, evaluate, and apply health-related information. Developing health literacy during adolescence is particularly important because students begin making independent decisions related to nutrition, hygiene, and lifestyle choices. Integrating microbiome education into biology instruction may therefore contribute to improved health awareness and informed decision-making.

Artificial intelligence technologies offer promising opportunities for addressing these educational challenges. AI-powered systems can provide personalized explanations, interactive simulations, and immediate feedback that facilitate meaningful learning experiences. Despite growing interest in AI-supported education, limited research has examined its role in developing microbiome literacy and health literacy among secondary school students.

The purpose of this study is to investigate the effectiveness of artificial intelligence technologies in enhancing microbiome literacy and health literacy among Grade 11 students in biology education.

Research Questions

How does AI-supported biology instruction influence microbiome literacy among Grade 11 students?

To what extent does AI-assisted learning improve students' health literacy?

What are students' perceptions of AI technologies in biology education?

Research Hypotheses

H1: Students receiving AI-supported instruction will demonstrate significantly higher microbiome literacy than students receiving traditional instruction.

H2: Students exposed to AI-supported learning will demonstrate higher levels of health literacy.

H3: Students will report positive perceptions regarding the use of AI technologies in biology education.

2. Literature Review

2.1 Artificial Intelligence in Biology Education

AI technologies have become increasingly important in science education. Research demonstrates that AI-supported learning environments improve engagement, motivation, and academic achievement. Adaptive learning systems personalize instruction according to students' needs, while generative AI applications facilitate inquiry-based learning and scientific exploration.

In biology education, AI tools enable students to visualize complex processes, analyze scientific information, and engage with interactive simulations. These capabilities are particularly valuable when teaching emerging scientific topics that require conceptual understanding rather than memorization.

2.2 Microbiome Literacy

The human microbiome consists of trillions of microorganisms that inhabit the body and contribute to physiological functions. Scientific research has linked microbiome diversity to immune function, metabolism, and disease prevention.

Microbiome literacy refers to understanding microbial ecosystems and their relationships with human health. Despite the growing significance of microbiome science, many students possess misconceptions regarding microorganisms and often fail to recognize their beneficial roles.

Integrating microbiome education into secondary school biology curricula may enhance scientific literacy and promote health awareness.

2.3 Health Literacy

Health literacy involves the ability to access, understand, evaluate, and apply health-related information. Educational institutions play a critical role in developing these competencies.

Students with higher health literacy levels are more likely to engage in healthy behaviors and make informed health decisions. Microbiome education may contribute to health literacy by helping students understand relationships among nutrition, lifestyle, microbial diversity, and overall well-being.

2.4 Research Gap

Although numerous studies have examined AI applications in education and health literacy development, limited research has explored AI-supported microbiome education among secondary school students. Existing studies primarily focus on higher education or medical training. Therefore, further investigation is needed to determine how AI technologies can support microbiome literacy and health literacy development in school biology education.

3. Methodology

3.1 Research Design

This study employs a quasi-experimental research design using a pre-test–post-test control group model.

The design was selected because it allows comparison of learning outcomes between students receiving AI-supported instruction and those receiving traditional instruction.

The study will involve:

- Experimental Group
- Control Group

Both groups will complete pre-tests and post-tests measuring microbiome literacy and health literacy.

Research Design Structure

Group	Pre-test	Intervention	Post-test
Experimental	O1	AI-supported learning	O2
Control	O1	Traditional instruction	O2

3.2 Participants

The study will be conducted among Grade 11 students enrolled in secondary schools.

Sample Size

Approximately 60–80 students will participate.

Group Distribution

Experimental Group:

- 30–40 students

Control Group:

- 30–40 students

Inclusion Criteria

Participants must:

- Be enrolled in Grade 11 Biology.
- Provide informed consent.
- Attend at least 80% of instructional sessions.

3.3 Educational Intervention

The intervention will last six weeks.

Students in the experimental group will learn microbiome-related topics through AI-supported activities integrated into biology lessons.

Topics Covered

Week 1:

Introduction to Microorganisms and the Human Microbiome

Week 2:

Microbiome Diversity and Ecosystem Functions

Week 3:

Gut Microbiota and Digestion

Week 4:

Microbiome and Immune System Regulation

Week 5:

Nutrition, Lifestyle, and Microbial Health

Week 6:

Microbiome and Disease Prevention

AI Tools Used

1. AI-generated quizzes
2. Interactive microbiome simulations
3. AI-powered visualizations
4. Adaptive learning platforms

Students in the control group will study identical content using traditional teaching methods, including lectures, textbooks, and classroom discussions.

3.4 Research Instruments

1. Microbiome Literacy Test

A researcher-developed assessment consisting of:

- 20 multiple-choice questions
- 5 short-answer questions

The instrument will measure:

- Knowledge of microbiome concepts
- Understanding of microbial functions
- Awareness of microbiome-health interactions

2. Health Literacy Questionnaire

The questionnaire will assess students' ability to:

- Access health information
- Understand health information
- Evaluate health information
- Apply health information

The questionnaire will contain 20 Likert-scale items.

3. Student Perception Survey

A survey will measure attitudes toward AI-supported learning.

Dimensions include:

- Perceived usefulness
- Ease of use
- Engagement
- Motivation

4. Semi-Structured Interviews

Interviews will be conducted with selected students after the intervention.

Sample interview questions:

- How did AI technologies influence your learning?
- Which AI tools were most useful?

- How has your understanding of microbiome-health relationships changed?

3.5 Data Collection Procedure

Phase 1: Preparation

- Obtain ethical approval.
- Develop instructional materials.
- Pilot test research instruments.

Phase 2: Pre-testing

Both groups complete:

- Microbiome Literacy Test
- Health Literacy Questionnaire

Phase 3: Intervention

Six-week instructional program.

Phase 4: Post-testing

Both groups complete:

- Microbiome Literacy Test
- Health Literacy Questionnaire
- Student Perception Survey

Phase 5: Interviews

Qualitative data collection from selected participants.

3.6 Data Analysis

Quantitative data will be analyzed using SPSS software.

Descriptive Statistics

- Mean
- Standard deviation
- Frequency
- Percentage

Inferential Statistics

Independent Samples t-test

Used to compare:

- Experimental group
- Control group

Paired Samples t-test

Used to compare:

- Pre-test scores
- Post-test scores

Effect Size

Cohen's d will be calculated to determine practical significance.

Qualitative Analysis

Interview data will be analyzed using thematic analysis.

The analysis process includes:

1. Transcription
2. Coding
3. Theme development
4. Interpretation

3.7 Ethical Considerations

The study will follow established ethical standards for educational research.

Key ethical principles include:

- Voluntary participation
- Informed consent
- Confidentiality
- Anonymity
- Right to withdraw

Parents and students will receive information regarding the purpose of the study and data collection procedures before participation.

4. Expected Results and Discussion

The study is expected to demonstrate that AI-supported biology instruction enhances microbiome literacy and health literacy among Grade 11 students. Students in the experimental group are expected to achieve higher post-test scores and report greater engagement compared to the control group.

AI technologies may facilitate learning by providing personalized explanations, interactive experiences, and immediate feedback. These features align with constructivist learning principles and may support deeper conceptual understanding of microbiome-related topics.

Improved health literacy is also anticipated because students will explore relationships between lifestyle factors and microbial health. Such understanding may contribute to healthier

decision-making and greater awareness of disease prevention strategies.

The anticipated findings may support the integration of AI technologies into biology education and highlight the educational value of microbiome-related content.

5. Conclusion

Artificial intelligence technologies offer significant opportunities for enhancing biology education and promoting health-related competencies. This study proposes an AI-supported instructional model designed to improve microbiome literacy and health literacy among Grade 11 students.

The proposed research contributes to educational innovation by integrating emerging biological content with advanced digital technologies. If successful, the intervention may provide valuable recommendations for curriculum development, teacher training, and the implementation of AI-supported learning environments in secondary education.

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Psychological Sciences

Healthcare Systems, Media, and Crisis Management: An Analysis of the U.S. Emergency Response Model

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Abstract

This article examines the interrelationship between emergency medical response systems and media communication during crisis situations, drawing on observations and professional experiences acquired through the 2025 International Visitor Leadership Program (IVLP) in the United States. The study is based on visits to healthcare institutions, emergency management agencies, and media organizations in Washington, D.C., Baltimore, Los Angeles, and Maine, providing insights into an integrated, multi-sectoral approach to crisis management.

Particular attention is devoted to the 2023 Lewiston mass shooting in Maine, which serves as a case study of effective coordination among healthcare providers, emergency response services, and communication networks. The analysis highlights the importance of pre-established emergency protocols, functional distribution of responsibilities among medical institutions, and strategic management of critical resources, particularly blood supplies, in ensuring an efficient response to mass-casualty incidents.

The study further explores the role of media as an essential component of emergency management. Beyond its traditional informational function, media serves as a mechanism for public mobilization, trust-building, and behavioral guidance during crises. The Lewiston case demonstrates how coordinated and accurate media communication facilitated the timely mobilization of blood donors, reduced public uncertainty, and supported effective resource allocation.

The findings suggest that successful emergency management depends on the integration of healthcare systems, emergency services, and media institutions within a coordinated communication framework. The U.S. experience, particularly the model observed in Maine, illustrates how strategic communication can enhance clinical effectiveness and public resilience. These findings offer valuable implications for countries such as Georgia, where the development of crisis communication strategies and emergency medical response systems remains an important policy and public health priority.

Keywords: Crisis Communication; Emergency Medical Response; Media and Public Health; Disaster Management; Mass Casualty Incidents.

Research Methodology

The present study employs a mixed-methods approach combining qualitative and quantitative research methods. This methodological framework enables a comprehensive examination of the relationship between healthcare systems and media institutions in emergency situations and

supports the argument that effective crisis management requires strong coordination between these sectors.

Empirical Observation and Case Analysis

The study draws on professional observations and experiences acquired during the 2025 International Visitor Leadership Program (IVLP) in the United States, including visits to healthcare and emergency management institutions in Maine, Baltimore, and Los Angeles. Particular attention is given to the emergency response model implemented in Lewiston, Maine, following the 2023 mass shooting incident. This case serves as an example of coordinated interaction among healthcare providers, emergency services, and communication networks during a large-scale crisis.

Quantitative Research

The study also incorporates findings from a survey conducted by the author as part of doctoral research. The survey included 501 respondents who evaluated the role of media during various emergency situations, including the COVID-19 pandemic. The quantitative data provide insights into public perceptions of media effectiveness in crisis communication and emergency management.

Descriptive Analysis

A descriptive analytical approach was applied to examine the dynamics of media communication during emergencies and its influence on public behavior, decision-making processes, and public health outcomes.

Theoretical Foundations of the Study

The theoretical basis of the research is grounded in scholarly literature on crisis communication and public health. Existing studies examine the ways in which media communication influences public behavior, emotional responses, and decision-making processes during emergencies. Within this framework, media is viewed not merely as a channel for information dissemination but as an active component of crisis management and public mobilization.

Theoretical Framework

The theoretical analysis focuses on two key dimensions:

Media Influence During Emergencies

Previous research (e.g., Garfin et al., 2020) demonstrates that media communication can have both positive and negative effects during crises. Accurate and responsible reporting may reduce uncertainty, foster public trust, and mitigate panic, whereas misinformation and excessive exposure may contribute to confusion, anxiety, and informational chaos.

Community Mobilization and Resource Management

The study also examines the role of communication strategies in facilitating community mobilization during emergencies. Effective communication enables healthcare systems to manage critical resources, such as blood supplies, by encouraging organized public participation rather than spontaneous and potentially disruptive responses.

These theoretical perspectives are integrated with the American case study, particularly the experience of Maine, and further supported by the findings of the author's survey research.

Scientific Novelty

The scientific novelty of the study is reflected in several key contributions:

Multisectoral Perspective on Emergency Response

The research examines emergency management beyond a purely clinical framework by analyzing the coordinated interaction among healthcare institutions, emergency response services, medical aviation, and media organizations.

Identification of the Transformative Role of Media

The study demonstrates that, during emergencies, media functions not only as a transmitter of information but also as an active mechanism influencing public behavior, strengthening trust, promoting collective responsibility, and facilitating social mobilization.

Adaptation of International Experience

Drawing on recent crisis management practices observed in the United States, particularly in Maine, the study proposes recommendations relevant to the development of healthcare communication systems and emergency preparedness strategies in Georgia.

Relevance of the Study

The relevance of this research is determined by the growing importance of effective communication in emergency situations, where the rapid dissemination of information can contribute either to public stability or to social disruption.

Several challenges underscore the significance of the issue:

Lack of Institutional Coordination

Insufficient coordination between healthcare institutions and communication systems often results in information gaps, inconsistent messaging, and increased public uncertainty during crises.

Challenges in Resource Mobilization

The effective management of critical resources, including blood and blood components, depends on the rapid yet organized engagement of the community. Without coordinated communication strategies, resource mobilization efforts may become inefficient and chaotic.

Local Context and Challenges

In Georgia, institutional communication mechanisms and media practices continue to face challenges during emergency situations. Therefore, studying successful international models and developing preventive cooperation frameworks between healthcare and media institutions represent important priorities for strengthening national crisis preparedness and response capacity.

Introduction

Emergency situations represent a significant challenge for contemporary societies, particularly when human life and health are at risk. Effective crisis management depends not only on the rapid delivery of medical services but also on efficient communication and timely dissemination of accurate information. Previous studies indicate that crisis communication significantly influences public behavior, reduces panic, and facilitates resource mobilization. In this context, the media serves as a critical instrument for both information dissemination and public engagement¹.

International Experience: Observations within the IVLP Program

This study draws upon observations conducted during the 2025 International Visitor Leadership Program (IVLP) in the United States. Professional visits to Washington, Baltimore, Los Angeles, and Maine provided insights into emergency preparedness and healthcare management practices.

The observations identified several key components of effective crisis response: interagency coordination, efficient blood supply management, rapid resource allocation, and strategic media communication. Despite regional differences, successful emergency management consistently relied on pre-established protocols, institutional coordination, and effective communication mechanisms.²

¹ Matthew Seeger, "Best Practices in Risk and Crisis Communication," *Journal of Risk Research* 9, no. 6 (2006): 601–610; Barbara Reynolds and Matthew Seeger, "Crisis and Emergency Risk Communication as an Integrative Model," *Journal of Health Communication* 10, no. 1 (2005): 43–55.

² America's Blood Centers, "Honoring visiting leaders from Georgia as part of the U.S. Department of State's International Visitor Leadership Program," LinkedIn, September 26,

The Lewiston Mass Shooting: Clinical and Communication Response

The 2023 mass shooting in Lewiston, Maine, provides an illustrative example of an integrated emergency response system. Regional healthcare institutions, including Maine Central Medical Center and St. Mary's Regional Medical Center, coordinated patient triage, stabilization, and treatment, while medical aviation services ensured rapid transportation of critically injured patients.

A particularly important aspect of the response was the mobilization of blood donors. Through coordinated communication based on official information sources, media organizations facilitated organized public participation and enabled the rapid collection of essential blood supplies. This case demonstrates the capacity of media communication to transform public concern into effective collective action.

The media response was characterized by the dissemination of verified information, regular public briefings, practical guidance, and targeted calls for community engagement. The collaboration between media organizations and the American Red Cross contributed significantly to resource management and public coordination during the crisis.

Comparison with the COVID-19 Pandemic

The American emergency response model emphasizes centralized communication and reliance on official information channels. However, evidence from the COVID-19 pandemic highlights the challenges associated with crisis communication in prolonged health emergencies.

Data from a survey of 501 respondents conducted as part of the author's doctoral research revealed substantial public dissatisfaction with media performance during the pandemic. A majority of respondents perceived media coverage as exaggerated or fear-inducing, while more than 90% believed that media communication contributed fully or partially to public panic. Furthermore, a significant proportion of respondents relied on informal sources of information, increasing the risk of misinformation and reduced trust in official health communication.

These findings contrast sharply with the Lewiston case, where coordinated communication supported social solidarity and effective resource mobilization. The comparison illustrates that media communication can either strengthen or undermine public resilience, depending on the quality, consistency, and credibility of information provided.

Conclusion

The findings demonstrate that effective emergency management requires the integration of healthcare systems, emergency services, and media institutions within a coordinated communication framework. The U.S. experience, particularly the Lewiston case, highlights the importance of multisectoral cooperation, strategic communication, and community mobilization during crises.

The study further confirms the transformative role of media in emergency situations. Beyond its informational function, media serves as a mechanism for shaping public behavior, strengthening trust, and facilitating collective action. Effective communication contributes to the organized management of critical resources and enhances overall crisis response capacity.

The findings offer practical implications for countries such as Georgia, where strengthening cooperation between healthcare institutions, emergency services, and media organizations remains an important priority for improving emergency preparedness and crisis communication.

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