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Economic Sciences

VISUAL CHOICE ARCHITECTURE IN DIGITAL MARKETING AS A FACTOR OF CONSUMER PERCEPTION AND CHOICE

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Abstract. The article examines how the visual architecture of a digital environment covertly shapes consumer choice. Drawing on recent scholarly publications (2022–2026), the study reveals the mechanisms through which an interface influences cognitive load and the allocation of attention. It is shown that the relationship between the salience of an element and the likelihood of purchase is not linear, and that the concept of total minimalism often loses out to meaningful visual complexity. The paper substantiates the idea that the visual environment functions as a filter that sets the boundaries of decision-making, while aggressive nudges can provoke a rejection effect. Special attention is paid to the hardware-based confirmation of these processes through eye-tracking methods.

Keywords: visual marketing, choice architecture, consumer perception, consumer choice, visual attention, cognitive load, digital nudges, e-commerce.

ВИЗУАЛЬНАЯ АРХИТЕКТУРА ВЫБОРА В ЦИФРОВОМ МАРКЕТИНГЕ КАК ФАКТОР ПОТРЕБИТЕЛЬСКОГО ВОСПРИЯТИЯ И ВЫБОРА

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Аннотация. В статье исследуется, как именно визуальная архитектура цифровой среды скрыто управляет потребительским выбором. Опираясь на актуальные научные публикации (2022–2026 гг.), работа раскрывает механизмы влияния интерфейса на когнитивную нагрузку и распределение внимания. Показано, что зависимость между заметностью элемента и вероятностью покупки не является линейной, а концепция тотального минимализма зачастую проигрывает осмысленной визуальной сложности. В работе обосновывается мысль о том, что визуальная среда функционирует как фильтр, задающий границы принятия решений, а агрессивные подталкивания могут вызывать эффект отторжения. Отдельное внимание уделено аппаратному подтверждению этих процессов через методы айтрекинга.

Ключевые слова: визуальный маркетинг, архитектура выбора, потребительское восприятие, потребительский выбор, визуальное внимание, когнитивная нагрузка, цифровые подталкивания, электронная коммерция.

Введение

Когда потребитель открывает приложение или сайт интернет-магазина, ему кажется, что он полностью контролирует процесс покупки. На деле его путь заранее спроектирован с помощью визуальной архитектуры выбора. Компоновка элементов, цветовые акценты, структура сеток и позиционирование товаров выступают невидимыми фильтрами, которые отсеивают одни варианты и выводят на первый план другие. Главный исследовательский вопрос заключается не в том, привлекает ли дизайн внимание, а в том, как именно человеческий мозг обрабатывает эти пространственные стимулы и в какой момент подсознательная реакция на интерфейс конвертируется в реальное экономическое решение.

Иллюзия свободы выбора: как интерфейс фильтрует альтернативы

Любой потребительский выбор начинается с визуального контакта. Если товар находится вне зоны видимости, для покупателя он физически не существует. Именно поэтому первичная навигация и алгоритмы интерфейса действуют как строгие привратники. Нестандартная, вовлекающая структура меню способна мгновенно вывести человека из режима автоматического скроллинга, повысив его эмоциональную вовлеченность в процесс (Wu, Li, & Hu, 2022).

Однако эта вовлеченность имеет смысл лишь в сочетании с алгоритмами выдачи. Позиция товара в ранжировании жестко лимитирует сам процесс поиска (Honka, Seiler, & Ursu, 2024). Пользователь физически не способен сравнить все доступные опции; он сравнивает лишь то, что визуальная архитектура позволила ему увидеть без чрезмерных когнитивных усилий. Таким образом, пространственная иерархия не столько напрямую «продает» товар, сколько формирует узкий, тщательно смоделированный коридор альтернатив. Внутри этого коридора покупатель и совершает свой «свободный» выбор, не осознавая, что сама матрица вариантов была задана за него.

Ловушка минимализма: когда визуальная сложность идет на пользу

Долгое время негласным стандартом UI/UX-дизайна считалось максимальное упрощение. Логика казалась безупречной: чем меньше элементов на экране, тем легче принять решение. Однако современные эмпирические данные демонстрируют парадоксальную картину — тотальное упрощение работает далеко не всегда.

Например, при выборе экологичных товаров более сложный, детализированный дизайн маркировки вызывает у покупателей больше доверия и повышает итоговую оценку продукта. Главное условие — эта сложность должна легко считываться мозгом (Donato & Adıgüzel, 2022). Похожий эффект наблюдается в стремительно развивающемся сегменте прямых продаж (live-streaming commerce). Насыщенный, динамичный задний фон не отвлекает зрителя, а, напротив, органично погружает его в атмосферу трансляции, парадоксальным образом снижая внутреннее когнитивное напряжение (Tong et al., 2023).

Проблема возникает лишь в том случае, когда сложность лишена структуры и превращается в хаос. Если пользователю вываливают десятки вариантов без четких визуальных акцентов, наступает перегрузка выбором (choice overload), которая парализует волю и ведет к отказу от покупки (Jacob, Thomas, & Joseph, 2024). Разница кроется в осмысленности контента: структурная сложность добавляет необходимый контекст и вовлекает, в то время как бессистемное нагромождение карточек создает лишь информационный шум.

Границы манипуляции: почему прямые подталкивания могут навредить

Стремясь максимизировать конверсию, платформы часто внедряют агрессивные визуальные стимулы (nudges): яркие стикеры «хит продаж», контрастные кнопки, предварительно выбранные опции по умолчанию. Визуальный контекст действительно способен кардинально менять восприятие выгоды. Ярким примером служит эффект порядка

представления цен: если показывать покупателю прайс-лист по возрастанию, он с гораздо большей вероятностью выберет дешевый товар, чем если бы те же самые цифры шли по убыванию (Mukherjee, 2022). Цветовые метки также доказали свою высокую эффективность при подталкивании аудитории к выбору здорового питания в онлайн-супермаркетах (Valenčič et al., 2023).

Но у этого мощного инструмента есть обратная сторона. Систематический анализ применения таких подталкиваний выявил тревожную тенденцию: если интерфейс «давит» слишком сильно, покупатель начинает осознавать факт манипуляции (Girotto & Nicolas, 2026). Это неминуемо вызывает психологическое сопротивление (реактанс) и резкое падение доверия к площадке. Гораздо более устойчивый и безопасный результат дают нативные решения. К примеру, грамотно выстроенная композиция товарного изображения, где сбалансированы фон и передний план, способна органично повысить готовность клиента платить, не вызывая при этом ощущения навязчивости (Chaudhuri, Gupta, & Lim, 2026).

Взгляд изнутри: скрытая механика биометрических данных

Понять истинные мотивы покупателя через классические опросы практически невозможно, поскольку большинство визуальных оценок происходит бессознательно, за доли секунды. Именно поэтому исследовательский фокус смещается в сторону аппаратных методов UX-исследований, в частности айтрекинга (отслеживания движений глаз).

Биометрические данные разрушают многие устоявшиеся стереотипы. Оказывается, яркий контрастный элемент действительно первым перехватывает взгляд (минимальное время до первой фиксации), но это совершенно не гарантирует совершение покупки. Истинным триггером финального решения выступает время удержания внимания (dwell time) на смысловых блоках интерфейса — например, на развернутых характеристиках продукта или зоне социальных доказательств (Mikalef et al., 2023). Человек сканирует страницу неравномерно: сначала он ищет визуальные «якоря» для базовой ориентации, а затем фокус замедляется там, где необходимо снизить потребительскую неопределенность. Айтрекинг доказывает, что путь к покупке — это цепочка микрорешений, где каждая зона экрана должна вовремя подхватить взгляд пользователя и плавно передать его дальше, к этапу конверсии.

Заключение

Цифровая среда — это не просто статичная витрина, а активный участник сделки. Архитектура выбора работает как невидимый консультант, который перераспределяет внимание, дозирует когнитивную нагрузку и гибко управляет издержками на поиск информации. Отказ от механического использования ярких триггеров в пользу глубокого понимания психологии зрительного восприятия позволяет брендам не только повышать сиюминутную конверсию, но и выстраивать долгосрочные отношения с потребителем. В условиях высочайшей конкуренции выигрывают те платформы, которые способны создать интерфейс, который мягко направляет покупателя, но при этом оставляет ему ощущение полного контроля над ситуацией.

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The First State Georgian Eurobonds – History and trends

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(abstract)
The paper reviews Georgia's first two sovereign Eurobond issues, USD 500 million at 7.5% in 2008 and USD 500 million at 6.875% in 2011. The second issue refinanced most of the first and extended its maturity. It looks at the investor base, ratings, price dynamics and spreads over U.S. Treasuries. The narrowing spread shows growing investor trust, but the funds went to budget spending instead of energy projects, which raises doubts about the borrowing.
Keywords: Georgian Eurobonds, sovereign debt, external debt, bond yield, credit spread, refinancing, EMBI index, London Stock Exchange

The First State Georgian Eurobonds – History and trends

Before reviewing the Georgian Eurobond market directly, it is worth briefly characterizing this instrument and explaining its international significance. There are several types of international bonds. On international exchanges, two instruments are the most in demand and the most developed: Euro-bonds, i.e., Eurobonds, and Euro-notes (Dictionary of Finance and Investment Terms, 1995: 167).

- Eurobonds are bonds that are placed simultaneously on the markets of several countries by international syndicates and are denominated in a currency that is not the national currency of either the borrower or the creditor. Euro-bonds are bearer securities that are deposited with depositaries in trading systems. These unregistered securities are placed mainly in developing countries. There is no need to reserve collateral behind them, which has made their issuance easier for issuers.
- Euro-notes are registered securities, issued in countries with developed market economies. Unlike Euro-bonds, the issuance of Euro-notes involves the creation of collateral.

In April 2008, Georgia placed debut Eurobonds worth USD 500 million on the London Stock Exchange. The placement was for a five-year term and was carried out through two banks, JP Morgan and UBS. The officially declared purpose of the Eurobond issue was to spend the funds raised on the construction of a gas storage facility and on investment in high-voltage power transmission lines.

The interest rate fixed on the Eurobonds was 7.5%(Reuters: http://www.reuters.com/article/2011/04/07/georgia-bond-idUSLDE7361VC20110407), which was adequate to the situation on the markets of the EU countries in this period (we reviewed the bond interest rates of EU countries in the previous chapters). However, in the same period on

world markets the yield on U.S. Treasury bonds was 2.75% (http://www.bloomberg.com/quote/BUSY:IND/chart); that is, because of the risk, the Georgian bond offered creditors an interest rate about three times higher.

Geographically, 47.8 percent of Georgia's Eurobonds were bought by Great Britain, 16.4 percent by the USA, 8.2 percent by the Netherlands, 6.9 percent by Germany, 4.6 percent by Denmark, 3.6 percent by France, 3.4 percent by Austria, 2.5 percent by Italy and 2.2 percent by Switzerland, while other countries bought 4.4 percent of the bonds.

Country	%
United Kingdom	47.8
USA	16.4
Netherlands	8.2
Germany	6.9
Denmark	4.6
France	3.6
Austria	3.4
Italy	2.5
Switzerland	2.2
Other countries	4.4

(Source: http://www.londonstockexchange.com/exchange/searchengine/search.html?lang=en&x=0&y=0&q=georgian+eurobonds)

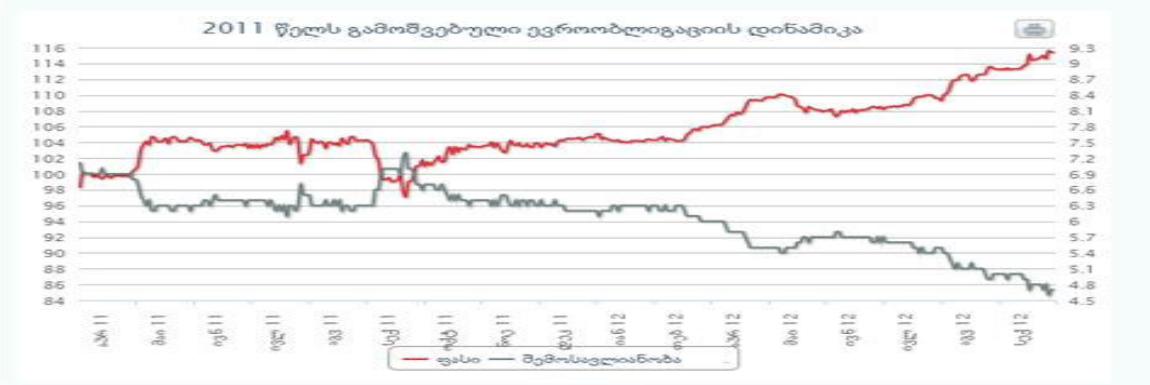
(According to London Stock Exchange data, for the price formation and yield of Georgian Eurobonds)

After the placement of the bonds, the Government of Georgia changed their intended use. Instead of investing in energy projects, the funds were placed in the treasury account and in the so-called "Future Fund" in order to accumulate them; during the 2008 war and in the wake of the subsequent crisis, this resource was used to finance the current expenditures of the state budget. It can be said that the funds received from the Eurobonds were used wastefully and resulted in yet another increase in Georgia's external debt.

The placement of Georgia's sovereign Eurobonds on the London Stock Exchange was carried out successfully; according to UBS (Union Bank of Switzerland), demand exceeded supply threefold. The reasons named were the country's successful economic reform, its successful credit history, and the fact that the Eurobonds would be taken into account in the future when calculating the JPMorgan EMBI index.

Second Eurobond Issue

In April 2011, the Government of Georgia issued 10-year bonds worth USD 500 million (Georgia issued new 500-million Eurobonds: http://civil.ge/geo/article.php?id=23886), with the interest rate fixed at 6.9%. The government refinanced the 2008 Eurobonds in the amount of USD 417 million; external debt increased by USD 83 million.



Source: National Bank of Georgia

To assess how successfully the Government of Georgia issued the new bonds, we should look at the difference (spread), recognized in the financial literature, between risk-free interest rates and the interest rates of the Eurobonds issued by Georgia. The interest rate on U.S. Treasury bonds is considered the risk-free interest rate.

On the other hand, using this instrument and its data is convenient for this type of comparison because it and the Eurobonds issued by Georgia are both denominated in dollars, which eliminates currency risk.

Interest rate on U.S. government securities (%)

Date	5-year	10-year
7 April 2008	2.75	3.57
5 April 2011	2.28	3.50

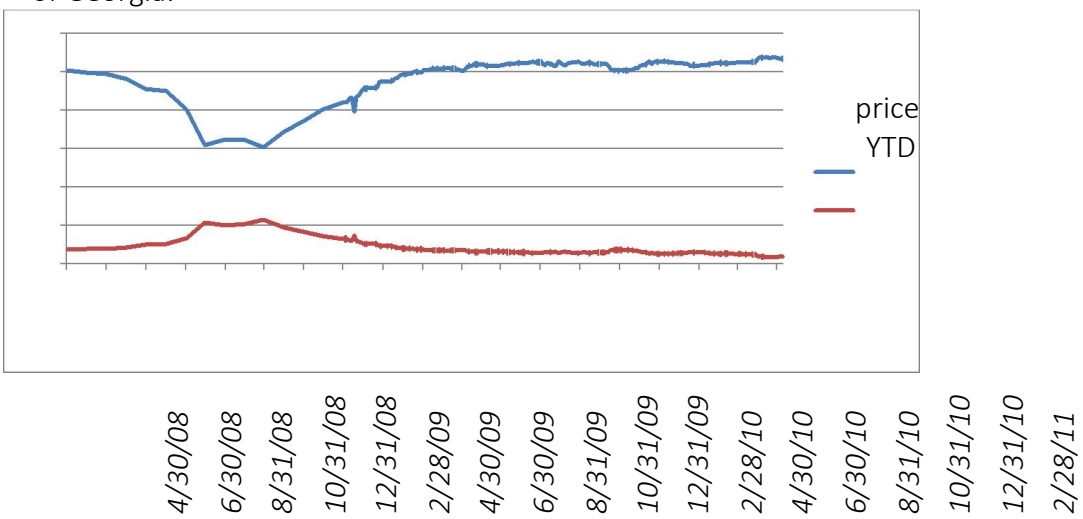
It is noteworthy that the yield on the new bond was 6.875%, which was only about twice the rate on U.S. 10-year government securities, indicating that trust in Georgia had increased compared with 2008.

It should be noted that the issuance of the Eurobonds introduced Georgia to the international capital markets and to many large institutional investors. In this respect, it was one of the key elements of the strategy to encourage the inflow of diversified capital into Georgia.

As already noted, the first placement of the Eurobonds took place on 7 April 2008. The coupon was 7.5 percent, paid twice a year; the maturity was to be 15 April 2013, with redemption in a single payment; and the minimum denomination was USD 100,000.

The underwriting of these bonds was carried out by the investment banks UBS and JP Morgan, and the bonds were registered on the London Stock Exchange (LSE). The rating agency Fitch assigned these bonds a BB- rating; on 25 September 2008, Standard & Poor's rated them B; and according to Moody's, on 6 October 2010 these bonds had a Ba3 rating.

Below we present the price dynamics of the first issue of the Eurobonds issued by the Government of Georgia:



(Source: London Stock Exchange, UBS)

As can be seen from the chart, the events of August 2008 significantly reduced the price of the Eurobonds, but the price of the bonds subsequently rose. This was a precondition for Georgia being able to move the maturity date of 83% of these bonds from 2013 to 2021, while the coupon rate fell from 7.5% to 6.875%, although the maturity lengthened.

On 7 April 2011, the Government of Georgia issued new Eurobonds worth USD 500 million and repurchased USD 417 million of the outstanding USD 500 million bonds with a 7.50% coupon due in 2013.

This transaction was carried out in accordance with Rule 144A, which allowed Georgia to broaden its investor base, in particular by attracting new investors from the United States. With this offering, Georgia's Eurobonds entered the index known as the EMBI benchmark, which is quite an important event. To be included in this index, debt issued by a country must have a maturity of more than one year, a value of more than USD 500 million, and meet strict trading requirements. Investors use the figures of this index to compare bonds of this type with the figures of various other financial instruments and, in general, to illustrate trends in the developing world.

It is also important to note that these bonds issued by the Government of Georgia were purchased by QIBs – qualified institutional investors. The latter include institutions, among them banks, savings and loan institutions, insurance companies, pension funds and other institutions that manage securities worth at least USD 100 million, or registered broker-dealers that manage securities worth at least USD 10 million.

However, despite this successful debut, from the issuance of the Eurobonds to the present day the question remains unanswered as to what the expediency of issuing Eurobonds was for Georgia at a time when the state budget was running a surplus, and why the intended use of the raised resources changed. It is also unclear why external debt of this size was taken on at a time when the global financial crisis had already begun.

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Observation of State Obligations Market of Georgia and the Deposit Certificate of The National Bank of Georgia – its issue and the purpose

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(abstract)
This paper surveys the types of government securities circulating in Georgia: treasury bills (since 1997), treasury bonds (since 2006), National Bank of Georgia deposit certificates (since 2006) and Eurobonds (since 2008). No municipal securities exist, which holds back the market and local self-government. The paper traces the treasury bonds to the 2006 restructuring of the government's debt to the National Bank. That restructuring ended direct central bank financing of the deficit and set repayment through 2030. It then describes deposit certificates, which replaced short-term deposit auctions as a liquidity tool open only to commercial banks. Their growing volumes and 2015-2016 issuance schedule show the banking sector's interest, but they are not accessible to the general public.
Keywords: Georgia, government securities, treasury bonds, treasury bills, deposit certificates, National Bank of Georgia, debt restructuring, open market operations, municipal securities.

Observation of State Obligations Market of Georgia and the Deposit Certificate of The National Bank of Georgia – its issue and the purpose.

In reviewing the legal basis for the issuance of government securities, we examined the following provisions: the 1997 Regulation "On the Issuance, Circulation, Accounting and Redemption of Treasury Bills and Treasury Bonds by the Ministry of Finance of Georgia," and the 2006 agreement between the Government of Georgia and the National Bank of Georgia, "On Measures for the Repayment of the Debt of the Government of Georgia to the National Bank of Georgia." According to these two provisions, two types of government securities circulate on the Georgian securities market: the Georgian treasury bill (since 1997) and the Georgian treasury bond (since 2006).
However, the research we conducted identified other government securities that circulate on the securities market. These are:

- Deposit certificates of the National Bank of Georgia (since 2006);
- Eurobonds issued by the Government of Georgia (since 2008).

It was established that no municipal government securities circulate on the Georgian securities market, which undoubtedly undermines the full-fledged development of the government securities market. At the same time, this type of security is a key prerequisite for the development of local self-government and for raising trust in municipalities.

We believe that in Georgia investment should be encouraged not only in government securities issued by the central government, but also in municipal securities to be issued by local self-governments in the future.

The absence of this type of security hinders local self-governments in strengthening their financial position and in solving the tasks facing them.

As the analysis showed, the four types of government securities mentioned above differ from one another by the following criteria:

1. The government body issuing the government security;
2. The date of issue of the government security;
3. The term of the government security to maturity;
4. The currency in which the government security is issued.

This fourth criterion concerns the Eurobonds issued by the Government of Georgia, which are bought and sold in foreign currency. The other government securities are issued in the national currency – the lari.

We have already discussed the legal aspects of the issuance and circulation of Georgian treasury bills and treasury bonds. The following subsections discuss the deposit certificates issued by the National Bank of Georgia and the Eurobonds.

Peculiarities of the Origin of Georgian Government Bonds

Since Georgia's independence, the government's debt to the National Bank grew steadily, and as of 15 March 2006 it amounted to GEL 832,846,323.50 (National Bank of Georgia, https://www.nbg.gov.ge/index.php?m=611).

Before directly reviewing the peculiarities of bond issuance in Georgia, we examined the method by which the debt accumulated:

From 1994 to 2006 the Ministry of Finance of Georgia used loans from the National Bank of Georgia to cover the budget deficit. That is, instead of the civilized path, which involves operations on the open market and relations with investors, Georgia in effect engaged in monetary issuance.

On 20 March 2006, the Government of Georgia and the National Bank of Georgia concluded the "Agreement on Measures for the Repayment of the Debt of the Government of Georgia to the National Bank of Georgia," under which the debt was restructured so that each year one part of the debt is converted into government bonds of various maturities for open market operations, while the other part is converted into a one-year debt obligation held to maturity, renewed annually.

On 15 May 2006, by order of the Minister of Finance of Georgia and the President of the National Bank of Georgia (Order №444/138), the Regulation "On the Issuance, Accounting, Circulation and Redemption of Government Bonds as a Result of the Restructuring of the Debt of the Government of Georgia to the National Bank of Georgia" was approved.

This type of government security is based on the National Bank of Georgia's "Rule and Special Regulation on the Sale and Registration of Government Bonds" (Order #335 of the President of the National Bank of Georgia). The regulation explains that a government bond is a coupon-bearing, medium-term government security, denominated in the national currency and issued in non-materialized form.

The debt will be fully repaid in 2030. The National Bank may use these bonds for open market operations.

The annual coupon rate payable on the bonds was set at 13% for 2006, 2007 and 2008, while the interest payable on the debt obligation was set at 7% per annum in 2006 and 6% in 2007 and 2008.

For the years after 2008, the coupon rate on the bonds and the annual interest rate on the debt obligations are set jointly by the government and the National Bank, taking market rates into account.

Under this agreement, and through the issuances and redemptions of these securities, the debt repayment schedule was fully laid out and the National Bank of Georgia acquired an important instrument. That is, the debt, which until then had simply been recorded on the National Bank's balance sheet, acquired a very important weight and function.

Moreover, the bonds are not the only positive outcome achieved through the agreement between the National Bank and the government. It also changed the relationship between the government and the National Bank: from now on, the government is not financed directly by the National Bank; government securities are issued instead. This was a milestone step, because financing of the budget deficit by the central bank is not considered part of a stable macroeconomic environment in any developed country. Conversely, when direct lending is prohibited, this is one of the guarantees, established by legislation, that there will be macroeconomic stability in Georgia.

According to the Regulation "On the Issuance, Accounting, Circulation and Redemption of Government Bonds as a Result of the Restructuring of the Debt of the Government of Georgia to the National Bank of Georgia," a government bond is a coupon-bearing government bond issued by the Ministry of Finance with a maturity of 16 to 60 months and a nominal value of GEL 1,000. The coupon is the annual yield (interest income) received by the holder of the government bond on predetermined dates during the life of the bond. The Monetary and Credit and Foreign Exchange Policy Commission of the National Bank sets the maximum volume of bonds to be sold and the maximum interest rate (that is, the rate above which the National Bank will not sell bonds). In general, bonds are long-term (for example, the maturity of U.S. government bonds, already discussed, reaches 30 years).

Under international practice, these securities are sold directly on the open market by the Ministry of Finance; in our case, given the existing reality, a debt restructuring took place instead.

For the purposes of accounting, reporting and circulation of this instrument, a number of technical appendices were approved.

Deposit Certificate of the National Bank of Georgia

On 5 September 2006, the National Bank of Georgia (NBG) (https://www.nbg.gov.ge/index.php?m=557) developed, and on 18 September 2006 issued, a new monetary instrument: the NBG deposit certificate with a maturity of up to one year, which is more convenient and acceptable for banks and, at the same time, promotes the development of the securities market. Deposit certificates are used to withdraw medium-term liquid funds from the banking system.

Deposit certificates are sold through auctions. Only commercial banks have the right to participate in the auction. Deposit certificates are issued in the national currency. The auction is based on the multiple-price method. At deposit certificate auctions an interest rate ceiling applies, above which a bid is not satisfied. At the current stage, the National Bank of Georgia offers commercial banks three-month and six-month deposit certificates.

Chronologically, the auctions of deposit certificates is shown by the National Bank of Georgia: (https://www.nbg.gov.ge/index.php?m=619&lng=geo):

Before this instrument was introduced, the National Bank of Georgia used deposit auctions. Holding deposit auctions is one of the instruments of the National Bank of Georgia's monetary and credit policy, but it was short-term (with a maturity from 1 day to 84 days). This instrument was actively used by the National Bank in 2003–2006. The first deposit auction took place on 27 October 2003.

The rate at one-day deposit auctions ranged from 1 to 2 percent per annum, although they were held only in 2003 and 2004. The last one-day deposit auction took place on 2 August 2004 (National Bank of Georgia: https://www.nbg.gov.ge/index.php?m=512).
In 2004–2006, other deposit auctions were held, with maturities of 27, 28, 35, 42, 43, 49, 56, 60, 70 and 84 days. The annual rate ranged from 5 to 10 percent.
Immediately before the introduction of deposit certificates, the situation was as follows: from June to August 2006, 23 deposit auctions were held. The total volume of the auctions was GEL 56.85 million, which exceeded the corresponding figure of the previous year (GEL 32.4 million) by 75.46%. The average interest rate over the year was 9.62%. In September, this instrument was replaced by the deposit certificate. At auctions of deposit certificates with maturities of one to three months, the maximum rate was set at 12%. In September–December 2006, 67 auctions of deposit certificates were held. The introduction of this instrument was quite a successful step. In subsequent years the instrument showed a growing trend, and of the 52 auctions announced during 2010, commercial banks purchased deposit certificates at everyone. During the year, deposit certificates worth GEL 946 million were placed, and deposit certificates with a nominal value of GEL 806 million were redeemed. During the first years, on the secondary securities market, just 8 transactions in National Bank of Georgia deposit certificates were made, with a total amount of GEL 12.5 million (National Bank of Georgia: https://www.nbg.gov.ge/index.php?m=512).
Compared with 2010, in 2011 the number of transactions in National Bank of Georgia deposit certificates on the secondary securities markets increased particularly sharply. In total in 2011, 52 transactions in deposit certificates were concluded on the secondary market, with a total amount of GEL 199.1 million (in 2010 only 8 transactions worth GEL 12.5 million were carried out) (National Bank of Georgia: https://www.nbg.gov.ge/index.php?m=512). The specific nature of the National Bank's deposit certificate, expressed in the limited scope of its purchase and use as collateral (an instrument intended only for commercial banks), does not allow us to regard it as a security accessible to the general public. Moreover, its function and purpose is to be only an open market instrument in the arsenal of the National Bank of Georgia, and it can be bought and sold only among commercial banks (National Bank of Georgia: https://www.nbg.gov.ge/index.php?m=512).
The development and improvement of this market in 2012–2014 enabled the National Bank to prepare and publish the issuance schedule for 2015–2016 (National Bank of Georgia: https://www.nbg.gov.ge/uploads/moneratypolicy/cd/30.09.2014_cd_calendar_2014_weliiv_kvartali_2015w.pdf). The schedule provides for 50 (fifty) issues, with stable maturities of 91 and 182 days: 25 issues of GEL 20 million each, i.e., a total of GEL 500 million of 91-day deposit certificates, and 25 issues of GEL 35 million each, i.e., a total of GEL 875 million of 182-day certificates. Analysis of this schedule allows us to conclude that this type of government security enjoys the interest of the banking sector and performs the functions assigned to it.

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XARİCİ BORCLANMA SİYASƏTİNDƏ MALİYYƏ RİSKLƏRİNİN İDARƏ EDİLMƏSİ

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Xülasə
Xarici borclanma dövlətin investisiya və büdcə ehtiyaclarını maliyyələşdirmək imkanı yaratsa da, valyuta, faiz, yenidən maliyyələşdirmə və şərti öhdəlik risklərini artırır. Məqalədə bu risklərin yaranma mexanizmləri və idarəetmə vasitələri Azərbaycan üzrə rəsmi məlumatlar əsasında araşdırılır. 2025-ci ilin yekunlarına dair dövlət auditi hesabatında xarici borcun həcminin azalması ilə yanaşı, dəyişkən faizli öhdəliklərin yüksək payı və orta ödəmə müddətinin qısalması qeydə alınmışdır. Həmin göstəricilər borcun ümumi məbləğinin aşağı düşməsinin bütün maliyyə risklərinin eyni vaxtda azaldığı anlamına gəlmədiyini göstərir. Valyuta və faiz şoklarına dair şərti həssaslıq hesablamaları borc portfelinin strukturunun ayrıca qiymətləndirilməsinin əhəmiyyətini aydınlaşdırır. Xarici borclanma qərarlarının orta müddətli strategiya, illik borcalma planı, büdcə proqnozları və dövlət zəmanətlərinin monitorinqi ilə əlaqələndirilməsi təklif olunur.
Açar sözlər: xarici borclanma, dövlət borcu, valyuta riski, faiz riski, yenidən maliyyələşdirmə, borc dayanıqlığı.

Abstract
External borrowing can finance public investment and budget needs, but it also exposes the sovereign to currency, interest-rate, refinancing, and contingent-liability risks. This article examines the mechanisms behind these risks and the instruments used to manage them, drawing on official data for Azerbaijan. The state audit report covering 2025 records a decline in external public debt alongside a substantial share of floating-rate liabilities and a shortening average repayment period. These developments indicate that a lower outstanding debt stock does not necessarily imply an equivalent decline in every financial risk. Illustrative sensitivity calculations for exchange-rate and interest-rate shocks clarify why debt composition requires separate assessment. The article argues for linking external borrowing decisions with a medium-term debt strategy, an annual borrowing plan, budget forecasts, and systematic monitoring of government guarantees. The proposed approach places repayment capacity and portfolio resilience ahead of short-term borrowing costs.
Keywords: external borrowing, public debt, exchange-rate risk, interest-rate risk, refinancing, debt sustainability.

Аннотация
Внешние заимствования позволяют финансировать государственные инвестиции и бюджетные потребности, но одновременно создают валютные, процентные, рефинансировочные риски и риски условных обязательств. В статье рассматриваются механизмы возникновения этих рисков и инструменты управления ими на основе официальных данных Азербайджана. В заключении государственного аудита за 2025 год наряду с сокращением внешнего государственного долга отмечены значительная доля обязательств с плавающей процентной ставкой и уменьшение среднего срока погашения. Эти изменения показывают, что снижение общего объёма долга не означает одновременного уменьшения всех финансовых рисков. Условные расчёты чувствительности к валютным и процентным шокам раскрывают значение структуры долгового портфеля.

Предлагается согласовывать решения о внешних заимствованиях со среднесрочной долговой стратегией, ежегодным планом заимствований, бюджетными прогнозами и систематическим мониторингом государственных гарантий. Приоритетом должны оставаться платёжеспособность и устойчивость долгового портфеля.
Ключевые слова: внешние заимствования, государственный долг, валютный риск, процентный риск, рефинансирование, долговая устойчивость.

GİRİŞ

Xarici borclanma dövlət maliyyəsinin mühüm alətlərindən biridir. O, bir tərəfdən, genişmiqyaslı infrastruktur və sosial layihələrin həyata keçirilməsinə, digər tərəfdən isə büdcənin müəyyən dövrlərdə yaranan maliyyə ehtiyaclarının qarşılanmasına xidmət edir. Bununla belə, borcun cəlb edilməsi ilə onun qaytarılması arasında illərlə davam edən müddət mövcuddur. Bu müddətdə valyuta məzənnəsi, beynəlxalq faiz dərəcələri, kapital bazarlarına çıxış imkanları və büdcə gəlirləri dəyişə bilər. Buna görə borclanma qərarının keyfiyyəti yalnız əldə edilən vəsaitin həcmindən və ilkin faiz dərəcəsindən asılı deyil. Həmin qərarın gələcək büdcə ödənişlərinə və iqtisadiyyatın mümkün sarsıntılara davamlılığına təsiri də qiymətləndirilməlidir.

Xarici borcun həddindən artıq artırılması risk yaradır, lakin aşağı borc göstəricisi də avtomatik təhlükəsizlik demək deyil. İki ölkənin xarici dövlət borcu ÜDM-ə nisbətdə eyni səviyyədə ola bilər. Borcun bir ölkədə uzunmüddətli və sabit faizli, digər ölkədə isə qısamüddətli və dəyişkən faizli olması onların maliyyə həssaslığını fərqləndirir. Eyni fərq valyuta tərkibi, kreditorların sayı, ödənişlərin illər üzrə cəmlənməsi və dövlət zəmanətləri səbəbindən də yaranır. Beynəlxalq borc idarəetmə prinsipləri maliyyələşmənin orta və uzun müddətdə mümkün qədər aşağı xərclə, lakin məqbul risk səviyyəsində təmin edilməsinə üstünlük verir [9, s.11].

Azərbaycan üçün mövzunun aktuallığı iqtisadiyyatın xarici qiymət dəyişikliklərinə həssaslığı, qeyri-neft gəlirlərinin genişləndirilməsi zərurəti və dövlət maliyyəsində ehtiyatların mühüm rolu ilə bağlıdır. Strateji valyuta ehtiyatlarının mövcudluğu borca xidmət imkanlarını dəstəkləyir. Lakin ehtiyatların yüksək olması borc portfelinin müddət, valyuta və faiz strukturuna nəzarəti əvəz etmir. Neft-qaz gəlirlərində mümkün dəyişikliklər, dövlət müəssisələrinin öhdəlikləri və maliyyə bazarlarında qiymətin dəyişməsi eyni dövrdə büdcə üzərində təzyiq yarada bilər. Həmin səbəbdən borcun dayanıqlılığı təkcə bu günə deyil, bir neçə il sonrakı ödəniş cədvəlinə əsaslanaraq qiymətləndirilməlidir. Məqalənin məqsədi xarici borclanma siyasətində əsas maliyyə risklərini ayırd etmək, onları ölçməyə imkan verən göstəriciləri müəyyənləşdirmək və Azərbaycan üzrə rəsmi statistik məlumatların yaratdığı idarəetmə nəticələrini əsaslandırmaqdır. Təhlildə normativ sənədlər, Hesablama Palatasının illik rəyində dərc edilmiş 2024–2025-ci il göstəriciləri, 2026-cı ilin rəsmi borc məlumatları və beynəlxalq metodoloji sənədlər müqayisə edilir. Nümunəvi hesablamalar yeni empirik müşahidə kimi deyil, mövcud borc göstəricilərinə müəyyən şok şərtlərinin tətbiqi ilə alınan həssaslıq təsvirləri kimi təqdim olunur. Belə yanaşma faktiki nəticə ilə ehtimal olunan ssenarini bir-birindən ayırmağa imkan verir.

ƏSAS HİSSƏ

Dövlətin xarici borcu ilə iqtisadiyyatın ümumi xarici borcu eyni anlayış deyil. Azərbaycan Respublikasının “Dövlət borcu haqqında” Qanununda xarici dövlət borcu dövlət adından qeyri-rezidentlərlə bağlanmış müqavilələr üzrə öhdəlik kimi müəyyən edilir. Bununla yanaşı, dövlət zəmanəti ilə cəlb edilən borc ayrıca hüquqi və maliyyə məzmunu daşıyır. Dövlət yalnız zəmanət şərtləri yarandıqda həmin öhdəliyin icrasına cəlb oluna bilər. Bu fərq statistikanın şərhi üçün vacibdir. Məsələn, qeyri-rezident qarşısında öhdəliyin olması onun mütləq ABŞ dollarında ifadə edildiyini göstərmir; xarici kreditor qarşısında milli valyuta ilə də borc yarana bilər. Eləcə də özəl sektorun xarici borcu avtomatik olaraq dövlət borcuna daxil edilmir [6]. Borc siyasətinin səmərəliliyi üç suala əsaslanır: vəsait hansı məqsədə cəlb edilir, hansı şərtlərlə qaytarılır və

mümkün mənfi dəyişikliklər zamanı ödəniş hansı mənbədən təmin ediləcək? Birinci sual layihənin iqtisadi və sosial səmərəsini, ikinci sual ödəniş profilini, üçüncü sual isə maliyyə dayanıqlığını əhatə edir. Borcun ucuz görünməsi onun faydalı olduğunu sübut etmir. Məsələn, dəyişkən faizli kreditin ilkin dəyəri sabit faizli kreditdən aşağı ola bilər, ancaq bazar faizləri yüksəldikdə həmin üstünlük itir. Kreditin seçilməsi zamanı ödənişin mümkün dəyişmə intervalı və büdcənin bu dəyişməni qarşılamaq imkanı birlikdə nəzərə alınmalıdır.

Valyuta riski xarici borclanmanın ən çox müzakirə edilən tərəflərindəndir. Borc xarici valyutada olduqda manatın həmin valyutaya nisbətən dəyərdən düşməsi əsas borcun və faiz ödənişlərinin manat ifadəsində artmasına səbəb olur. Bu təsir yalnız dövlətin birbaşa borcları ilə məhdudlaşmır. Dövlət zəmanəti olan, lakin gəliri əsasən manatla formalaşan müəssisənin borc yükü də arta bilər. Valyuta riski hesablanarkən borcun hansı valyutada ifadə edildiyi, gəlirlərin valyuta mənbələri və ödənişlərin müddəti ayrıca yoxlanmalıdır. Uzun müddət sabit qalan məzənnəni gələcək dövrlər üçün dəyişməz fərziyyə kimi götürmək maliyyə planlamasında həssaslığı gizlədir. Azərbaycan iqtisadiyyatında ixracdan xarici valyuta daxilolmaları valyuta mövqeyinin ümumi qiymətləndirilməsində mühüm rol oynayır. Lakin ixrac gəlirlərinin dövlət büdcəsinə daxil olma mexanizmi ilə ayrı-ayrı xarici borc ödənişləri arasında birbaşa və dəyişməz uyğunluq mövcud deyil. Buna görə ölkənin geniş valyuta imkanları ilə konkret borc müqaviləsinin valyuta riski fərqli səviyyələrdə qiymətləndirilməlidir. Ehtiyatların mövcudluğu borca xidmətin təhlükəsizlik yastığıdır, amma həmin vəsaitlərin hamısını hər hansı ödəniş tarixində istifadə edilə bilən sərbəst büdcə vəsaiti kimi qəbul etmək düzgün olmaz. Aktivlərin likvidliyi, hüquqi rejimi və ehtiyatlardan istifadə siyasəti də nəzərə alınmalıdır.

Faiz dərəcəsi riski borcun dəyərinin vaxt keçdikcə dəyişməsi ilə bağlıdır. Sabit faizli müqavilədə kredit üzrə kupon və ya faiz ödənişi əvvəlcədən müəyyən edilir, dəyişkən faizli müqavilədə isə ödəniş seçilmiş bazar göstəricisinə bağlanır. SOFR və EURIBOR kimi dərəcələrin yüksəlməsi müvafiq müqavilələrin növbəti yenilənmə tarixlərində xidmət xərclərini artırır. Bu zaman risk yalnız kreditin həcminə deyil, dərəcənin neçə aydan bir yenilənməsinə və müqavilədə nəzərdə tutulan əlavəyə də bağlıdır. Məsələn, eyni həcmdə iki dəyişkən faizli borcun yenilənmə tarixləri fərqli olduqda faiz şoku onların büdcəyə təsirini müxtəlif vaxtlarda göstərəcək. Faiz riskinin idarə edilməsində sabit və dəyişkən faizli borclar arasında balans vacibdir. Dəyişkən faizli öhdəliklər həmişə daha əlverişsiz deyil; faizlərin enməsi zamanı onların xərci azala bilər. Sabit faizli borc isə proqnozlaşdırılan ödənişə şərait yaradır, lakin ilkin qiyməti yüksək ola bilər. Optimal seçim konkret ölkənin bazara çıxış şərtləri, büdcə dözümlülüyü və borc portfelində mövcud paylarla bağlıdır. Bir istiqamətə ifrat üstünlük verilməsi gələcək çevikliyi azaldır. Beynəlxalq təlimat borcalma alətlərinin xərc və riskinin ayrıca ssenarilər üzrə yoxlanmasını, borc strategiyasının isə orta müddətli fiskal çərçivə ilə uyğunlaşdırılmasını tövsiyə edir [10, s.11].

Yenidən maliyyələşdirmə riski mövcud borcun qaytarılma vaxtı çatanda yeni maliyyələşmə mənbəyinin kifayət qədər münasib şərtlərlə tapılmaması ehtimalıdır. Borcun müəyyən bir ildə böyük hissəsinin ödənişə düşməsi dövlətin bazar şəraitindən asılılığını gücləndirir. Dünya maliyyə bazarlarında likvidlik azaldıqda və ya investorların riskə münasibəti sərtləşdikdə borcun yenilənməsi çətinləşə, yeni borcun qiyməti arta bilər. Bu səbəbdən borc qalığının aşağı düşməsi ilə yanaşı, müddət profilinin necə dəyişdiyi də əsas göstəricidir. Ödənişlər illər üzrə nisbətən bərabər paylandıqda bir maliyyə ilinə düşən təzyiq azalır. Yenidən maliyyələşdirmə riskini qiymətləndirərkən orta ödəmə müddəti, növbəti 12 ayda ödəniləcək əsas borcun payı və illik ümumi maliyyələşmə tələbi birlikdə təhlil edilir. Orta ödəmə müddəti portfelin ümumi istiqamətini göstərsə də, təkbaşına kifayət etmir. Eyni orta göstəriciyə malik iki portfeldə birində böyük həcmli ödəmə bir tarixə, digərində isə bir neçə ilə yayıla bilər. Bu fərqi müəyyən etmək üçün ayrıca ödəniş qrafiki lazımdır. Maliyyə ehtiyacının mövsümi dəyişməsi də önəmlidir. Vergi daxilolmalarının zəif olduğu ayda iri borc ödənişinin cəmlənməsi qısamüddətli likvidlik gərginliyini artıra bilər.

Likvidlik riski ilə yenidən maliyyələşdirmə riski bir-birini tamamlayır, lakin eyni hadisə deyil. Dövlətin uzunmüddətli ödəmə qabiliyyəti saxlanılsa belə, müəyyən tarixdə kifayət qədər sərbəst pul vəsaiti olmaya bilər. Digər tərəfdən, qısamüddətli likvidlik ehtiyatı böyük olduqda da yüksək borc yükünün davamlı maliyyələşməsi problemli qala bilər. Buna görə xəzinədarlıq üzrə pul axınlarının proqnozu borc ödəniş təqvimi ilə uzlaşdırılmalıdır. İnvestor tələbinin azaldığı dövrdə əvvəlcədən formalaşdırılmış pul ehtiyatı vaxtında ödənişə kömək edə bilər, ancaq bu ehtiyatın saxlanması da müəyyən xərc tələb edir. Şərti öhdəliklər xarici borclanma siyasətinin görünməyən hissəsini formalaşdıra bilər. Birbaşa dövlət borcu müqavilə bağlanan andan qeydiyyata alınır, dövlət zəmanətləri üzrə isə dövlətin faktiki ödənişi müəyyən şərtin yaranmasından asılı olur. Borc statistikası hazırlanarkən birbaşa borcla zəmanətli borcu mexaniki şəkildə toplamaq ikiqat sayma təhlükəsi yarada bilər. Digər tərəfdən, zəmanət öhdəliklərini ümumiyyətlə nəzərə almamaq risk miqyasını kiçildə bilər. Düzgün yanaşma birbaşa borcu və zəmanət portfelini ayrıca göstərmək, üst-üstə düşən mövqeləri ayırmaq və mümkün büdcə xərcini ssenarilər üzrə qiymətləndirməkdir.

Ölkə və kreditor konsentrasiyası da maliyyə risklərinin vacib mənbəyidir. Borcun əhəmiyyətli hissəsinin bir valyutaya, bir neçə kreditora və ya müəyyən maliyyə alətinə bağlı olması eyni xarici hadisədən yaranan təsirin güclənməsinə səbəb ola bilər. Məsələn, bir kreditor qrupunun maliyyələşmə siyasətini dəyişməsi yeni kreditlərin əldə edilməsini çətinləşdirir. Digər tərəfdən, müxtəlif mənbələrdən borc cəlbi həmişə ucuzluq demək deyil; hüquqi şərtlər və əlavə komissiyalar fərqli ola bilər. Məqsəd kreditorların sayını süni artırmaq deyil, maliyyələşmə imkanlarını müqayisə edə və əlverişsiz şərtlərdən asılılığı azalda bilən portfel qurmaqdır.

Borcla maliyyələşdirilən layihələrin icrası da maliyyə riskləri ilə bağlıdır. Layihə gecikdikdə kredit üzrə ödənişlər başlasa da, nəzərdə tutulan iqtisadi fayda və xidmət həcmi vaxtında yaranmaya bilər. Tikinti, satınalma və icazə prosesləri ilə bağlı gecikmələr vəsaitdən istifadə ilə borca xidmət arasında uyğunsuzluq yaradır. Buna görə yeni xarici kredit üzrə qərar yalnız maliyyə şərtləri ilə deyil, layihənin hazırlıq səviyyəsi, texniki-iqtisadi əsaslandırması və icraçı qurumun hesabatlılığı ilə birlikdə qəbul edilməlidir. İnvestisiya layihəsinə cəlb edilən kreditin sosial faydasını ölçmək hər zaman asan deyil, lakin ödəniş cədvəli və maliyyə öhdəliyi əvvəlcədən məlum olmalıdır. İdarəetmə riskinin ayrı qiymətləndirilməsi də əhəmiyyətlidir. Borc müqavilələrinin qeyri-dəqiq qeydiyyatı, xarici və daxili borc haqqında məlumatların ayrı sistemlərdə saxlanması, dövlət zəmanətlərinə dair gecikmiş hesabat və səlahiyyət bölgüsünün aydın olmaması risklərin vaxtında aşkarlanmasını çətinləşdirir. Beynəlxalq DeMPA metodologiyasında hüquqi çərçivə, təşkilati quruluş, borc strategiyası, audit, uçot, borc məlumatlarının hesabatlılığı və pul axınlarının proqnozu ayrıca qiymətləndirmə istiqamətləridir. Burada məqsəd rəqəmlərin çoxaldılması deyil, qərar qəbul edənlərin eyni məlumatı vaxtında və uyğun formada əldə etməsidir [12, s.8].

Borclanmanın büdcə siyasətindən təcrid olunmuş formada aparılması əlavə risk yaradır. Büdcə kəsiri böyüdükdə və ya gəlirlərin daxilolma vaxtı dəyişdikdə borclanmaya tələbat gözlənilən dən artıq ola bilər. Həmin dövrdə bazar faizləri yüksəlibsə, dövlət daha bahalı maliyyələşmə ilə üzləşir. Buna görə orta müddətli borc strategiyası xərclərin və gəlirlərin proqnozu, fiskal qaydalar və makroiqtisadi ssenarilərlə eyni əsas fərziyyələrdən istifadə etməlidir. Borc idarəçiliyinin düzgün aparılması fiskal siyasətin problemlərini tam həll etmir, lakin onların borc xidmətinə çevrilmə sürətini və miqyasını məhdudlaşdıra bilər.

Beynəlxalq təcrübədə risklərin dəyərləndirilməsi üçün borcun ÜDM-ə nisbəti, xarici borcun ümumi dövlət borcundakı payı, dəyişkən faizli öhdəliklərin xüsusi çəkisi, orta ödəmə və faiz yenilənmə müddətləri geniş istifadə edilir. Bununla yanaşı, ildə cəlb ediləcək yeni borcun miqdarı ilə həmin ildə qaytarılacaq əsas borcun cəmi, faiz ödənişləri və mümkün zəmanət xərcləri ayrıca izlənməlidir. Göstəricilər birgə şərh olunanda daha faydalıdır. Xarici borcun ÜDM-ə nisbəti azalsa da, eyni vaxtda onun orta müddətinin qısalması borc riskinin bütün komponentlərinin yaxşılaşmadığını göstərə bilər. Maliyyə risklərini idarə etmək üçün portfelin mövcud vəziyyətini düzgün təsvir edən məlumat bazası zəruridir. Hər bir müqavilə üzrə kreditin məbləği, valyutası, faiz

mexanizmi, ödəniş tarixi, yenilənmə tezliyi, kreditoru və zəmanət statusu elektron uçotda vahid qaydada görünməlidir. Layihəyə bağlı kreditlə büdcə kəsirinin maliyyələşdirilməsi üçün alınan vəsaitlər eyni texniki sistemdə izlənə bilər, lakin onların iqtisadi məqsədi ayrıca qeyd olunmalıdır. Belə qeydiyyat yalnız illik hesabat üçün deyil, faizlərin gözlənilmədən yüksəldiyi və ya valyuta bazarında gərginlik yarandığı dövrdə təcili hesablamaların aparılması üçün lazımdır.

Dövlət borcunun idarə edilməsinə dair 2022–2025-ci illər üzrə yenilənmiş strateji çərçivə Azərbaycan üçün xərc və risk balansını, dövlət borcunun idarəolunan səviyyəsini və yerli maliyyə bazarlarının inkişafını mühüm hədəflər kimi müəyyən edirdi. Həmin sənəd yalnız yeni borcalmaya deyil, mövcud borc və dövlət zəmanətləri üzrə vəziyyətə, gözlənilən risklərə və görüləcək tədbirlərə də aid idi. Strategiyada həmçinin xarici borcun daxili borcla mərhələli əvəzlənməsi və valyuta riskinin azaldılması məsələləri yer almışdı [5, s.2].

Göstərici	2024-cü ilin sonu	2025-ci ilin sonu	2026-cı il, 1 iyul
Birbaşa xarici dövlət borcu, mln ABŞ dolları	5 129,7	4 813,5	4 616,8
Birbaşa xarici borcun ümumi dövlət borcunda payı	mənbədə fərqli tarix üzrə	31,5%	32,9%
Dəyişkən faizli xarici borcun payı	49,3%	49,5%	eyni göstərici təqdim edilmir
Xarici borcun orta ödəmə müddəti	5,4 il	5,1 il	eyni göstərici təqdim edilmir

Cədvəl 1. Azərbaycan üzrə xarici dövlət borcunun seçilmiş göstəriciləri

Mənbə: Hesablama Palatasının 2025-ci il üzrə rəyi, s. 125–127; Maliyyə Nazirliyinin 2026-cı ilin I yarımili üzrə Statistik Bülleteni.

2025-ci ilin yekunları üzrə xarici dövlət borcunun məbləği 4 813,5 milyon ABŞ dolları təşkil etmişdir. Bu, əvvəlki ilin sonundakı 5 129,7 milyon ABŞ dollarından 316,2 milyon dollar və ya təxminən 6,2 faiz azdır. Hesablama Palatasının rəyində azalma həmin il cəlb edilən 106,8 milyon dollarlıq vəsaitlə müqayisədə əsas borc üzrə 472,8 milyon dollarlıq ödənişin aparılması ilə əlaqələndirilir. Bununla yanaşı, xarici valyutaların ABŞ dollarına nisbətən möhkəmlənməsi borcun dollar ifadəsinə 49,8 milyon dollarlıq artırıcı təsir göstərmişdir. Burada qiymətləndirmə fərqi ilə faktiki yeni borclanma bir-birindən ayrılmalıdır [3, s.125].

Xarici dövlət borcunun azalması maliyyə intizamı baxımından müsbət dəyişiklikdir, amma struktur göstəriciləri daha mürəkkəb mənzərə yaradır. 2025-ci ilin sonuna xarici borcun 50,5 faizi sabit, 49,5 faizi isə dəyişkən faiz dərəcəsi ilə cəlb edilmiş öhdəliklərdən ibarət idi. Dəyişkən faizli borcun məbləği əvvəlki illə müqayisədə azalsa da, onun xüsusi çəkisi 49,3 faizdən 49,5 faizə yüksəlmişdir. Faiz riskinin qiymətləndirilməsi üçün belə fərq əhəmiyyətlidir. Borcun ümumi məbləği azaldığı halda, qalan portfeldə faiz dərəcəsinin dəyişməsinə həssas hissənin payı artmışdır. Deməli, rəqəmin bir istiqamətdə dəyişməsi risklərin hamısının eyni istiqamətdə hərəkət etməsi anlamına gəlmir [3, s.126].

2025-ci ildə xarici dövlət borcunun valyuta tərkibində ABŞ dolları üstün mövqeyini qorumuşdur. Audit hesabatında dollarla ifadə edilən borcun 4 123,8 milyon ABŞ dolları ekvivalenti və ya portfelin 85,7 faizi olduğu göstərilir. Avro ilə ifadə olunan borcun payı 6,4 faiz, xüsusi borcalma hüquqları üzrə öhdəliklərin payı 3,2 faiz, yapon yeni üzrə 3,1 faiz, digər valyutalar üzrə isə 1,6 faiz təşkil etmişdir. Bu quruluşda dolların payı yüksək olduğundan manatın dollar qarşısında

mümkün dəyər dəyişikliyi büdcənin valyuta mövqeyi üçün xüsusi əhəmiyyət daşıyır. Digər valyutalar isə dollarla hesabat verilərkən əlavə qiymətləndirmə fərqi yaradır [3, s.126].

Ödəniş müddətləri ilə bağlı məlumatlar risk qiymətləndirməsində ayrıca diqqət tələb edir. 2025-ci ilin sonunda beş ilə qədər ödəmə müddəti qalan xarici borclar 2 802,0 milyon ABŞ dolları təşkil etmiş, onların portfeldə payı 58,2 faizə yüksəlmişdir. 2024-cü ildə bu pay 49,0 faiz olmuşdu. Beş ildən on ilə qədər ödəmə müddəti olan borcların payı isə 44,9 faizdən 36,1 faizə enmişdir. Bu dəyişiklik portfeldə yaxın və orta müddətli ödənişlərin nisbətən artdığını göstərir. Başqa sözlə, borc qalığı azalsa da, yeni vəsait cəlb etmədən qaytarılmalı məbləğlərin zaman üzrə bölgüsü daha diqqətli planlama tələb edir [3, s.127].

Audit rəyində xarici dövlət borcunun orta ödəmə müddətinin 2024-cü ilin sonunda 5,4 ildən 2025-ci ilin sonunda 5,1 ilə düşdüyü qeyd olunur. Göstəricinin 0,3 il azalması təkbaşına böhran əlaməti deyil. Bununla belə, eyni anda beş ilədək qalan müddətli borcların payının yüksəlməsi ilə birlikdə götürüldükdə portfelin gələcək ödəniş cədvəlinə diqqəti artırır. Müddət göstəricisi yeni borc müqavilələrinin bağlanması, vaxtından əvvəl ödənişlər və mövcud borcların təbii olaraq qaytarılma tarixinə yaxınlaşması nəticəsində dəyişə bilər. Hansı səbəbin üstün olduğunu bilmək üçün müqavilə səviyyəsində ödəniş axınları təhlil edilməlidir.

2025-ci ildə Azərbaycan hökumətinin beynəlxalq maliyyə təşkilatları ilə dəyişkən faizli kredit sazişləri bağlaması da faiz riskinin aktual qaldığını göstərir. Hesablama Palatasının sənədində Dünya Bankı ilə SOFR üzərinə 1,04 faiz bəndi, Asiya İnkişaf Bankı ilə SOFR üzərinə 0,5 faiz bəndi, Avropa Yenidənqurma və İnkişaf Bankı ilə isə EURIBOR üzərinə 1,0 faiz bəndi əlavə edilən müqavilələr göstərilir. Sazişin nominal dərəcəsini müəyyən edən göstərici dəyişdiyindən gözlənilən faiz xərci də dəyişir. Kreditorun institusional etibarlılığı bazar göstəricisinə bağlı faiz riskini avtomatik aradan qaldırmır [3, s.125].

2026-cı ilin birinci yarısının sonunda xarici dövlət borcu 4 616,8 milyon ABŞ dolları, ümumi dövlət borcu isə 23 830,6 milyon manat olmuşdur. Rəsmi yarımillik bülletenə görə, xarici borcun ümumi dövlət borcunda payı 32,9 faiz təşkil edib. Bu tarixə ümumi borc portfelində dəyişkən faizli öhdəliklərin payı 16,3 faiz olmuşdur. Burada mühüm metodoloji fərq var: 2025-ci il üçün göstərilən 49,5 faiz yalnız xarici borc portfelinin, 2026-cı ilin yarımillik məlumatındakı 16,3 faiz isə ümumi dövlət borcunun göstəricisidir. Bu iki rəqəmi birbaşa müqayisə edib faiz riskinin birdən-birə kəskin azaldığını söyləmək doğru olmaz [4].

Dövlət Statistika Komitəsinin 30 sentyabr 2026-cı il üzrə məlumatında xarici dövlət borcu 4 509,5 milyon ABŞ dolları, strateji valyuta ehtiyatları isə 89 380,7 milyon ABŞ dolları kimi göstərilmişdir. Xarici dövlət borcunun 1 iyul göstəricisi ilə müqayisədə 107,3 milyon dollar aşağı olması həmin dövrdə borc qalığının azalması deməkdir. Lakin bu məlumat ödəniş müddətinin və faiz strukturunun eyni dövrdə necə dəyişdiyini açıqlamır. Buna görə son göstərici qiymətləndirilərkən əvvəlki audit hesabatlarında aşkar edilmiş struktur riskləri ayrıca nəzarət mövzusu olaraq qalır [1].

2026-cı ilin maliyyə göstəricilərində strateji valyuta ehtiyatlarının xarici dövlət borcundan dəfələrlə yüksək olması ölkənin xarici ödəniş qabiliyyətini dəstəkləyən amildir. Bununla yanaşı, ehtiyatların borca nisbətini birbaşa dövlətin istənilən vaxt sərbəst istifadə edə biləcəyi büdcə mənbəyi kimi şərh etmək olmaz. Ehtiyatların mülkiyyət və idarəetmə strukturu, investisiya məqsədləri, likvidlik səviyyəsi və istifadə üçün nəzərdə tutulan hüquqi mexanizmlər fərqlənir. Həmin səbəbdən risk analizində dövlətin ümumi maliyyə ehtiyatları və bir illik büdcə likvidliyi ayrı göstəricilər kimi qiymətləndirilməlidir. Beynəlxalq Valyuta Fondunun Azərbaycan üzrə 2026-cı il hesabatında dövlət borcu üzrə ümumi stres riskinin aşağı, uzunmüddətli riskin isə orta səviyyədə olduğu vurğulanır. Hesabat iqtisadiyyatın karbohidrogen gəlirlərindən asılılığının tədricən azaldılması, qeyri-neft fiskal mövqeyinin gücləndirilməsi və dövlət müəssisələrinin maliyyə fəaliyyətinə nəzarətin genişləndirilməsini vacib hesab edir. Bu nəticə xarici borcun yalnız bugünkü

xidmət xərcləri əsasında deyil, büdcə gəlirlərinin uzunmüddətli dayanıqlığı çərçivəsində qiymətləndirilməsinin zəruriliyini təsdiqləyir [8, s.35].

Xarici borc göstəriciləri arasındakı fərqlərin mühüm hissəsi statistik əhatə dairəsindən yaranır. Dövlət borcu, dövlət zəmanətli borc, bütövlükdə dövlət sektoru borcu və ölkənin ümumi xarici borcu müxtəlif kateqoriyalardır. Bir göstəricidə mülkiyyət meyarı, digərində rezidentlik meyarı, üçüncüdə isə zəmanətin hüquqi statusu əsas götürülə bilər. İki müxtəlif sənəddən götürülən rəqəmlərin eyni cədvələ yerləşdirilməsi yalnız vahid tərif və tarixlə mümkün olduqda elmi məna daşıyır. Əks halda artım və ya azalma kimi görünən fərq əslində uçot çərçivəsinin dəyişməsi ola bilər. Dövlət borcunun idarə olunmasında hesabatlılıq bu səbəbdən riskin ölçülməsinin ilkin şərtidir.

Borc portfelinin strukturunu qiymətləndirmək üçün sadə həssaslıq hesablamaları faydalı başlanğıcdır. Burada iqtisadi proqnoz deyil, müəyyən şərt daxilində hesablanan mümkün təsir göstərilir. Məsələn, 2025-ci ilin sonunda xarici dövlət borcunun manat ifadəsində məbləği 8 183,0 milyon manat olmuşdur. Fərz edək ki, həmin məbləğin hamısı xarici valyuta məzənnəsinin manata nisbətdə eyni vaxtda 10 faiz yüksəlməsinə məruz qalır və digər şərtlər dəyişmir. Bu halda borcun manatla qiymətləndirilmiş qalığı təqribən 818,3 milyon manat artardı. Bu rəqəm yeni kredit və ya illik əlavə ödəniş deyil; yalnız məzənnə dəyişikliyinin borcun balans dəyərinə şərti təsiridir.

Faiz həssaslığı üçün də oxşar qayda tətbiq edilə bilər. 2025-ci ilin sonunda xarici borc portfelində dəyişkən faizli öhdəliklər təxminən 2 381,4 milyon ABŞ dolları idi. Əgər həmin öhdəliklərin hamısına tətbiq edilən istinad dərəcəsi 2 faiz bəndi artarsa və artım bütün il ərzində tam şəkildə qüvvədə olarsa, illik əlavə faiz xərci təqribən 47,6 milyon ABŞ dolları alınar. Hesablama 2 381,4 × 0,02 əməliyyatına əsaslanır. Real büdcə təsiri isə faiz yenilənmə tarixləri, kredit qalıqlarının ilboyu azalması, fərqli istinad dərəcələri və müqavilə şərtləri səbəbindən bundan başqa ola bilər. Bu nəticə faktiki yaranmış xərc kimi təqdim edilməməlidir.

Valyuta və faiz ssenarilərinin paralel tətbiqi risklər arasında əlaqəni daha aydın göstərir. Valyuta şoku xarici borcun manat ekvivalentinə, faiz şoku isə dəyişkən faizli kreditlərin xidmət dəyərinə təsir edir. Hər iki dəyişiklik eyni vaxtda baş verərsə, büdcə həm əsas borc üzrə daha yüksək manat məbləği, həm də əlavə faiz ödənişi ilə qarşılaşa bilər. Bununla belə, ssenarilərdəki iki rəqəmin sadəcə toplanması düzgün olmaz. Onlar müxtəlif ölçü vahidlərinə və müxtəlif maliyyə anlayışlarına aiddir. Müqayisə üçün bütün ödənişlərin konkret illər üzrə vahid valyutada pul axınına çevrilməsi, eyni anda borc qalığının da yenidən hesablanması tələb olunur.

Şərti ssenarilər real proqnozu əvəz etmir, amma qərar qəbul edən şəxs üçün portfelin zəif nöqtələrini görünən edir. İllik büdcə layihəsi hazırlanarkən baza ssenari ilə yanaşı, faizlərin yüksəldiyi, xarici maliyyələşmənin gecikdiyi, valyuta daxilolmalarının zəiflədiyi və iri dövlət zəmanətinin işə düşdüyü vəziyyətlər yoxlana bilər. Ssenarilərin bir-birindən tam müstəqil götürülməsi də yanıltıcıdır. Neft qiymətinin enməsi həm büdcə gəlirlərini azalda, həm də investorların riskə münasibətini sərtləşdirə bilər. Eyni şokun bir neçə kanal vasitəsilə təsirini nəzərə almaq maliyyə dayanıqlığının daha real qiymətləndirilməsinə şərait yaradır. İqtisadi cəhətdən səmərəli risk idarəçiliyi bütün risklərin sıfıra endirilməsi demək deyil. Belə hədəf həm mümkün deyil, həm də çox bahalı maliyyələşməyə səbəb ola bilər. Borcun daha uzun müddətə, sabit faizlə və mümkün qədər milli valyutada yerləşdirilməsi riskin bir hissəsini azalda bilər, lakin faiz və emissiya xərcləri artarsa, büdcə üçün ümumi nəticə fərqli olacaq. Mühüm məsələ riskə görə ödənilən əlavə xərcin nə qədər əsaslı olduğunu müəyyən etməkdir. Borc idarəetmə strategiyası buna görə yalnız seçilən aləti deyil, alternativlərdən niyə imtina edildiyini də sənədləşdirməlidir.

Dövlətin xarici borclanma siyasətini təkmilləşdirmək üçün orta müddətli strategiyanın hər il yenilənməsi məqsədəuyğundur. Strategiyada məqsəd və məhdudiyyətlər, borcun mövcud tərkibi, alternativ maliyyələşdirmə mənbələri və risk göstəricilərinin hədəf diapazonları bir-biri ilə bağlı olmalıdır. Dünya Bankı və Beynəlxalq Valyuta Fondunun metodologiyası əvvəlcə mövcud portfelin xərc və risk xüsusiyyətlərinin müəyyənləşdirilməsini, sonra isə alternativ borcalma strategiyalarının

eyni makroiqtisadi fərziyyələr altında müqayisəsini nəzərdə tutur. Bu müqayisə maliyyələşdirmə qərarlarını yalnız bir kreditin faiz dərəcəsinə görə verməyin qarşısını alır [10, s.18].

Strategiyanın gündəlik icraya keçirilməsi ayrıca illik borcalma planı tələb edir. Belə plan müəyyən il ərzində qaytarılacaq əsas borcu, faiz ödənişlərini, büdcə kəsirini, nağd vəsait axınlarını və yeni kreditlərin nəzərdə tutulan vaxtını uzlaşdırır. Bir illik plan orta müddətli strateji hədəfləri dəyişmək üçün deyil, onları illik əməliyyatlara çevirmək üçündür. Qısamüddətli borc ödəmələrinin bir neçə ayda toplanması və planlaşdırılan kreditin vəsaitinin gec daxil olması halında alternativ maliyyələşmə üsulları əvvəlcədən müəyyən edilə bilər. Bu planın hazırlanması xəzinədarlıqla borc idarəetmə qurumunun işini bir-birinə bağlayır [7, s.4].

Borcun yerləşdirilməsi ilə pul siyasətinin əlaqələndirilməsi də zəruridir. Dövlət qiymətli kağızlarının böyük həcmdə eyni vaxtda bazara çıxarılması bank sistemində likvidliyə təsir edə bilər. Mərkəzi Bankın eyni dövrdə həyata keçirdiyi pul bazarı əməliyyatları ilə uzlaşma olmadıqda bazar iştirakçılarının vəsaitə tələbi dəyişər və yerləşdirmənin qiyməti arta bilər. Bu səbəbdən dövlətin daxili borc bazarını inkişaf etdirməsi maliyyə risklərinin müəyyən hissəsini azaltmaqla yanaşı, pul bazarı ilə operativ koordinasiya tələb edir. Xarici və daxili borc mənbələrinin əvəzlənməsi barədə qərar yalnız valyuta riskinin azalmasına görə deyil, daxili bazarın həcmi və maliyyələşmə qiyməti də nəzərə alınmaqla qiymətləndirilməlidir.

Yerli valyutada dövlət istiqrazları bazarının genişlənməsi uzun müddətdə xarici valyuta borcundan asılılığı azalda bilər. Lakin yerli bazarın inkişafı bir qərarla baş vermir. Müntəzəm emissiya təqvimi, aydın hərrac prosedurları, müxtəlif müddətli istiqrazlar, formalaşmış investor bazası və etibarlı hesablaşma sistemi lazımdır. Bazarda yalnız qısamüddətli alətlərə tələbat varsa, xarici uzunmüddətli borcun sürətlə daxili qısamüddətli borcla əvəz edilməsi valyuta riskini azaldarkən yenidən maliyyələşdirmə riskini yüksəldə bilər. Bu səbəbdən valyuta və müddət göstəricilərinin birlikdə optimallaşdırılması daha əsaslıdır [11, s.24].

Yeni xarici kredit seçilərkən maliyyə xərclərinin tam məbləği açıqlanmalıdır. Təkcə müqavilədəki nominal faiz dərəcəsi deyil, ilkin komissiya, istifadə edilməmiş vəsaitə görə ödəniş, valyuta çevrilməsi xərci, mümkün hüquqi öhdəliklər və kreditin vaxtından əvvəl bağlanması şərtləri də hesaba daxil edilməlidir. Müxtəlif alətləri müqayisə etmək üçün gözlənilən pul axınlarının eyni qiymətləndirmə bazasına gətirilməsi vacibdir. Uzun müddətli güzəştli kreditin nominal faizinin aşağı olması onun hər şəraitdə sərfəli olduğu mənasını vermir; layihənin icra hazırlığı və vəsaitdən istifadə imkanları da müəyyənedicidir. Maliyyə risklərinin idarə olunması zamanı dövlət zəmanəti verilən qurumların fəaliyyəti ayrıca nəzarətdə saxlanmalıdır. Zəmanət verilən müəssisənin öz gəlirləri ilə əsas borcu və faizləri qarşılamaq qabiliyyəti yoxlanmalı, müəssisənin xarici valyuta gəliri olmadığı halda məzənnə dəyişikliklərinin ödənişlərə təsiri ayrıca hesablanmalıdır. Müqavilə bağlandıqdan sonra monitorinq dayandırıla bilməz. Müəssisənin xərclərinin artması, satış gəlirlərinin zəifləməsi və investisiya proqramının gecikməsi şərti dövlət öhdəliyinin büdcə xərcinə çevrilmə ehtimalını yüksəldir. Zəmanətlər üzrə məlumatlar birbaşa dövlət borcundan ayrıca dərc edilməli və qiymətləndirmədə üst-üstə düşən məbləğlər ayırd olunmalıdır. Təminat və ehtiyat mexanizmləri riskə cavab vermək üçün istifadə oluna bilər. Lakin belə fondların mövcudluğu müvəffəqiyyətsiz kredit və investisiya qərarlarının xərcini aradan qaldırmır. Dövlət zəmanəti verilən layihənin gəlir proqnozu qeyri-real olduqda ehtiyat fondu yalnız ödənişin vaxtında həyata keçirilməsini təmin edə bilər, layihənin iqtisadi səmərəliliyini bərpa etmir. Bu səbəbdən zəmanətin verilməsi mərhələsi, zəmanət üzrə riskin dövri yenilənməsi və mümkün ödəniş üçün ehtiyatın müəyyən edilməsi vahid prosesin hissələridir. Eyni nəzarət mexanizmləri dövlətin yenidən borc verdiyi müəssisələrə də tətbiq edilməlidir.

Risk limitləri praktikada seçilmiş göstəricilər üzrə müəyyən edilməlidir. Xarici valyuta borcunun ümumi borcdakı payı, növbəti ildə ödəniləcək əsas borcun miqdarı, dəyişkən faizli borcun çəkisi və zəmanət üzrə mümkün xərclər ayrıca izlənə bilər. Lakin limitlər iqtisadi vəziyyət dəyişdikdə avtomatik yenilənməməlidir. Hər bir dəyişiklik izahlı şəkildə əsaslandırılmalı, strategiyanın hansı

məqsədinə xidmət etdiyi göstərilməlidir. Bu qayda həm borc bazarının etimadını, həm də maliyyə idarəetməsinin hesabatlılığını gücləndirir. Risk göstəricilərinin rəqəmləri ilə yanaşı onların hesablanma üsulunun açıqlanması da vacibdir. İdarəetmə mexanizminin təşkilati quruluşu şəffaf olmalıdır. Kreditin cəlb edilməsinə dair danışıqları aparan, onun xərc və riskini qiymətləndirən və ödəniş əməliyyatlarını icra edən funksiyalar arasında qarşılıqlı nəzarət qurulması səhv və uyğunsuzluq ehtimalını azaldır. Beynəlxalq metodologiyada bu funksiyalar ön ofis, risk təhlili və arxa ofis kimi fərqləndirilə bilər. Onların müstəqilliyi tam ayrılıq mənasına gəlmir; əksinə, eyni məlumat bazası üzərində aydın səlahiyyət və məsuliyyət bölgüsünün qurulmasını tələb edir. Hesabatın ictimaiyyət üçün nəzərdə tutulan hissəsi ilə daxili risk hesabatı da məqsədinə uyğun fərqləndirilməlidir [12, s.18].

Borc məlumatlarının açıqlanması yalnız ümumi rəqəmin elan edilməsi ilə məhdudlaşmamalıdır. İctimaiyyət üçün dərc edilən məlumatda xarici və daxili borcun bölgüsü, kreditor kateqoriyaları, faiz və valyuta quruluşu, müddət profili, zəmanətlər və seçilmiş risk limitlərinin icrası üzrə əsas məlumatların olması qərarların qiymətləndirilməsini asanlaşdırır. Bununla yanaşı, məxfi kommersiya şərtləri ilə ictimai marağa aid toplu məlumat arasında tarazlıq saxlanmalıdır. Bir göstərici dəyişdikdə onun səbəbinin izah edilməsi daha faydalıdır. Məsələn, valyuta ilə ifadə olunan borc artımının yeni cəlb edilmiş kreditdənmi, yoxsa məzənnə qiymətləndirilməsindənmi qaynaqlandığı göstərilməlidir.

Borc üzrə stres sınaqlarının nəticələri büdcə planlamasına daxil edilməlidir. Xarici faiz dərəcələrinin yüksəldiyi şəraitdə əlavə xərclərin hansı illərə düşəcəyi, valyuta şokunda isə manat ekvivalenti üzrə borc qalığının və ödənişlərin necə dəyişəcəyi hesablanmalıdır. Bundan əlavə, layihə gəlirlərinin gecikməsi və dövlət zəmanətinin işə düşməsi eyni ssenaridə qiymətləndirilə bilər. Stres sınağının məqsədi mütləq bir dəqiq proqnoz almaq deyil, hansı həddən sonra mövcud pul axınlarının kifayət etmədiyini müəyyənləşdirməkdir. Riskin yarandığı məqam müəyyənləşəndə ehtiyat, borclanma limiti və əlavə tədbir barədə qərar da daha əsaslı olur. Maliyyə şoklarının qiymətləndirilməsində zaman amili nəzərdən qaçmamalıdır. Faiz dərəcəsinin artması bu gün müəyyən edilə bilər, lakin onun müqavilə üzrə növbəti yenilənmə tarixinə qədər real ödənişə təsiri olmaya bilər. Eyni qaydada xarici valyutada borcun manat ekvivalentinin artması dərhal əlavə büdcə ödənişi tələb etmir; növbəti ödəniş tarixi yaxınlaşdıqda onun əhəmiyyəti yüksəlir. Buna görə portfel riski illik orta rəqəmlərlə məhdudlaşmadan rüblük və mümkün olduqda aylıq pul axını üzrə ölçülməlidir. Həssaslıq hesablamasında müddət və yenilənmə tezliyinin göstərilməsi belə yanlış təəssüratların qarşısını alır.

Borc idarəçiliyi üçün yalnız maliyyə göstəricilərinə deyil, xarici kreditin istifadə nəticələrinə də baxmaq lazımdır. Dövlətin iqtisadi məhsuldarlığı artıran layihəyə cəlb etdiyi vəsait gələcək büdcə imkanlarını genişləndirə bilər. Əksinə, layihənin gecikməsi və ya xərclərinin ilkin hesablamadan çox olması uzunmüddətli borc xidmətini əlavə yükə çevirir. Layihənin ümumi faydası ilə birbaşa pul gəliri fərqli anlayışlardır. Məsələn, sosial infrastruktur layihəsi gəliri birbaşa formalaşdırmaya bilər, lakin onun səmərəsi başqa iqtisadi göstəricilərlə qiymətləndirilə bilər. Maliyyə risklərinin idarə olunması borclanma səbəbinin də əsaslandırılmasını tələb edir. Müasir xarici borclanma siyasətində ən mühüm seçimlərdən biri yeni mənbə cəlb etmək ilə mövcud borcu dəyişdirmək arasındadır. Dövlət müəyyən dövrdə yeni xarici borc götürmədən də mövcud portfelin riskini idarə edə bilər. Vaxtından əvvəl ödəniş, daha münasib şərtlə yenidən maliyyələşdirmə, borcun müddətinin uzadılması və uyğun olduqda faiz dərəcəsinin dəyişdirilməsi bu məqsədə xidmət edir. Həmin əməliyyatların maliyyə nəticələri açıq hesablanmalıdır. Vaxtından əvvəl ödəniş üçün cərimə, yeni kreditin komissiyası və alternativ olaraq ehtiyatın saxlanmasının faydası nəzərə alınmazsa, riskin azaldılması əlavə xərclə nəticələnə bilər.

Ümumi maliyyə dayanıqlığı baxımından neft-qaz gəlirlərinin dövlət büdcəsində çəkisi ayrıca diqqət tələb edir. Xam neft qiymətinin düşməsi və ya hasilatın azalması dövlət gəlirlərinin gözlənilən səviyyədən kənara çıxmasına səbəb ola bilər. Əgər belə dövrdə böyük xarici ödənişlər

də eyni vaxtda baş verərsə, borca xidmətin büdcədə xüsusi çəkisi yüksələr. Bu halda risk borcun məbləğindən daha çox gəlirlər və ödənişlər arasındakı uyğunsuzluqdan yaranır. Buna görə qeyri-neft gəlirlərinin genişləndirilməsi və xərclərin ortamüddətli qaydada planlaşdırılması borc dayanıqlığına xidmət edən ümumi iqtisadi tədbirlərdir. Risklərin əlaqəli xarakteri dövlətin aktivləri ilə öhdəliklərini birlikdə nəzərdən keçirməyə əsas verir. Xarici valyutada aktivlər riskin müəyyən hissəsini yumşalda bilər, lakin aktivlə borcun valyutası və müddəti eyni deyilsə, tam qorunma yaranmır. Eyni söz faiz mexanizminə də aiddir. Dəyişkən faizli aktivlərin gəliri ilə dəyişkən faizli borcun xərci bəzən eyni istiqamətdə hərəkət edir, lakin məbləğlər, müqavilə göstəriciləri və yenilənmə tarixləri fərqlidirsə, əlavə risk qalır. Dövlət aktivləri və öhdəlikləri arasında bu uyğunluğun qiymətləndirilməsi iri şokların büdcəyə xalis təsirini anlamaq üçün əhəmiyyətlidir [9, s.28].

Nəticələrin izlənməsi üçün bir neçə göstərici üzrə rüblük nəzarət cədvəli məqsədəuyğundur. Valyuta konsentrasiyası, dəyişkən faizli borcun payı, bir il ərzində ödəniləcək əsas borc, borc xidmətinin büdcə xərclərində payı və dövlət zəmanətinin mümkün büdcə təsiri cədvəldə ayrıca yer almalıdır. Göstəricilərdən hər hansı biri həddə yaxınlaşdıqda bunun səbəbi, mümkün düzəldici tədbir və tədbirin təxmini maliyyə dəyəri təqdim olunmalıdır. Bu təklifin mahiyyəti yeni bir statistik indikator icad etmək deyil; mövcud məlumatları qərar qəbulunda istifadə ediləcək ardıcıl hesabat formasına salmaqdır.

Risk istiqaməti	İzlənəcək göstərici	Uyğun idarəetmə addımı
Valyuta	Borcun valyutalar üzrə payı; illik xarici valyuta ödənişləri	Valyuta axınlarının uyğunlaşdırılması; şok ssenarisi
Faiz	Dəyişkən faizli pay; növbəti yenilənmə tarixi	Sabit və dəyişkən faizli alətlər üzrə xərc-risk müqayisəsi
Yenidən maliyyələşdirmə	12 ayda ödəniləcək borc; orta ödəmə müddəti	Ödənişlərin illər üzrə yayılması; illik borcalma planı
Likvidlik	Aylıq pul çatışmazlığı; likvid vəsait ehtiyatı	Xəzinə axınının planlaşdırılması; ehtiyat limiti
Dövlət zəmanəti	Zəmanət verilən borc; müəssisənin ödəniş qabiliyyəti	Monitorinq; şərti öhdəlik üzrə ehtiyat ssenarisi

Cədvəl 2. Xarici borclanma üzrə əsas maliyyə riskləri üçün monitorinq çərçivəsi

Mənbə: Müəllif tərfindən təklif edilmişdir.

Təklif edilən monitorinq çərçivəsi borcun müxtəlif risklərini eyni formada təqdim etməyə imkan verir. Valyuta və faiz risklərinin bir göstərici ilə, yenidən maliyyələşdirmə və likvidlik risklərinin başqa göstərici ilə izləndiyi nəzərə alınır. Cədvəldəki meyarlar qərarın qəbulundan əvvəl və sonra müqayisə oluna bilər. Məsələn, xarici kredit hesabına maliyyələşən yeni layihə ümumi borc məbləğini artırsa da, portfelin orta ödəmə müddətini uzada bilər. Belə dəyişiklik yalnız borcun artması kimi təqdim olunmamalı, onun risk profilinə birgə təsiri də şərh edilməlidir. Gələcək borclanma qərarlarında nəticələrin izahı qədər onların nəzarətdə saxlanması da önəmlidir. İlkin planın faktiki icrası ilə müqayisəsi zamanı vəsaitin nə qədərinin cəlb edildiyi, hansı tarixlərdə ödənişin aparıldığı və orta faiz dəyərinin necə dəyişdiyi yoxlanmalıdır. Borc planından kənaraçıxma həmişə mənfi idarəçilik demək deyil; bəzən bazar şəraitində daha münasib şərtlər yaranır.

Risklərə nəzarət mexanizminin faydası yalnız dövlət büdcəsi üçün deyil, iqtisadi subyektlər üçün də əhəmiyyət daşıyır. Borcun məqsədyönlü idarə edilməsi dövlət qiymətli kağızları bazarında proqnozlaşdırılanlıq yaradır, uzunmüddətli faiz göstəricilərinin formalaşmasına kömək edə və özəl sektor üçün qiymət siqnalı verə bilər. Əksinə, iri həcmli gözlənilməz borclanma əməliyyatları bazarın likvidliyinə və maliyyələşmə dəyərinə təsir edə bilər. Bu təsirin miqyası ölkədən ölkəyə

dəyişir, ona görə yerli bazarın dərinliyi və investor tərkibi nəzərə alınmalıdır. Dövlət borcunun idarə edilməsi pul və fiskal siyasətdən ayrı olsa da, onların nəticələrinə bağlıdır. Xarici borclanma siyasətində maliyyə risklərinin səmərəli idarəsi üçün borcun azaldılması, daha ucuz vəsait tapılması və yerli maliyyə bazarının inkişafı arasında tarazlıq qurulmalıdır. Bu məqsədlər bəzən eyni istiqamətə xidmət edir, bəzən isə bir-biri ilə ziddiyyətə girir. Xarici borcun daha tez qaytarılması gələcək faiz yükünü azalda, amma xəzinənin likvid ehtiyatlarını daralda bilər. Daxili borcun artırılması valyuta riskini məhdudlaşdıra, amma yüksək yerli faizlər səbəbindən büdcə xərclərini yüksəldə bilər. Düzgün seçim bu fərqlərin açıq hesablanmasına və maliyyə qərarının mümkün şoklar qarşısında yoxlanmasına əsaslanmalıdır.

NƏTİCƏ

Xarici borclanma dövlətin maliyyə resurslarını genişləndirən alət olmaqla yanaşı, gələcək illər üçün müəyyən ödəniş öhdəliyi yaradır. Onun iqtisadi səmərəsi yalnız borcun ümumi həcminə və ilkin faiz şərtlərinə görə qiymətləndirilə bilməz. Valyuta quruluşu, sabit və dəyişkən faizli borcların nisbəti, əsas borcun qaytarılma müddəti, likvidlik imkanları və dövlət zəmanətlərinin şərti təsiri birlikdə nəzərə alınmalıdır. Bu göstəricilərin birində yaxşılaşma digərlərində riskin azaldığını həmişə təsdiqləmir. Azərbaycan üzrə 2025-ci ilin rəsmi göstəricilərində xarici dövlət borcunun azalması ilə yanaşı, dəyişkən faizli öhdəliklərin portfeldə yüksək payı və orta ödəmə müddətinin qısalması müşahidə edilmişdir. Həmin dəyişikliklərin birgə qiymətləndirilməsi borc siyasətində məbləğ göstəricisinin ayrıca və yekun meyar kimi götürülməsinin məhdudluğunu üzə çıxarır. Şərti valyuta və faiz həssaslığı hesablamaları da riskin borc strukturundan və müqavilə şərtlərindən asılı olduğunu göstərir. Bu hesablamalar müşahidə edilmiş itki deyil, mümkün təsirin qiymətləndirilməsi üsuludur. Xarici borclanmanın idarə edilməsində orta müddətli strategiyanın illik borcalma planına çevrilməsi, ödəniş təqviminin büdcə və xəzinə axınları ilə uyğunlaşdırılması, dövlət zəmanətlərinin ayrı monitorinqi və əsas risk göstəricilərinin müntəzəm açıqlanması vacibdir. Yeni maliyyələşmə barədə qərar qəbul edilməzdən əvvəl onun təkcə ilkin qiyməti deyil, mövcud portfelin valyuta, faiz və müddət göstəricilərinə təsiri də yoxlanmalıdır. İdarəetmənin əsas məqsədi borcun mütləq sıfırlanması deyil, dövlətin maliyyələşmə ehtiyaclarının dayanıqlı qaydada və məqbul risklə ödənilməsidir.

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УПРАВЛЕНИЕ БИЗНЕС-ПРОЦЕССАМИ И ИХ ЦИФРОВИЗАЦИЯ: ПОЧЕМУ ТЕХНОЛОГИЧЕСКИЕ ИЗМЕНЕНИЯ НЕ ВСЕГДА ПРИВОДЯТ К ОРГАНИЗАЦИОННОМУ РЕЗУЛЬТАТУ

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Аннотация
Цифровизация бизнес-процессов открывает новые возможности для повышения эффективности организаций, однако внедрение современных технологий далеко не всегда приводит к улучшению конечных результатов деятельности. Ускорение отдельных операций может сопровождаться сохранением прежних организационных ограничений, дублированием управленческих решений и несогласованностью действий подразделений. Возникает закономерный исследовательский вопрос: при каких условиях технологические изменения действительно преобразуют сквозной бизнес-процесс, а не ограничиваются совершенствованием отдельных его элементов? В статье данная проблема рассматривается на основе критического концептуального анализа научных исследований, опубликованных за 2022–2026 гг. Сопоставление существующих подходов позволяет выявить различия между технической успешностью цифровых проектов, зрелостью процессного управления и фактической результативностью организационной деятельности. Предлагается рассматривать цифровизацию через взаимосвязь процессной определенности, глубины организационных изменений, межфункциональной интеграции и управленческой обратной связи. Особое внимание уделяется ситуациям, в которых недостаточная согласованность этих элементов препятствует достижению ожидаемых результатов. Обосновывается также возможность обратного влияния: цифровые технологии способны не только опираться на сформированные практики управления бизнес-процессами, но и создавать предпосылки для их дальнейшего развития.
Ключевые слова: управление бизнес-процессами; BPM; цифровизация; процессная зрелость; межфункциональная интеграция; process mining; результативность.

Введение

У цифрового проекта, как правило, есть ясный технический предмет - заменить бумажное согласование электронным, исключить повторный ввод сведений, сократить время регистрации заявки. Именно такие задачи легко включить в бюджет и техническое задание. Но предприятие может выполнить проект в срок, не приблизившись к результату, ради которого затевались изменения. Документ быстрее поступает к следующему участнику - и по-прежнему ожидает решения. Данные передаются автоматически - и все же несколько подразделений запрашивают одинаковые подтверждения. Объяснять это только несовершенством программного обеспечения было бы ошибкой: источник задержки нередко лежит в распределении полномочий и в самом устройстве совместной работы.

Поэтому необходимо развести два вопроса, которые в практике управления часто соединяют. Первый - заработало ли цифровое решение в соответствии с требованиями? Второй - стал ли весь процесс создавать результат быстрее, надежнее и с меньшими полными затратами? Положительный ответ на первый вопрос не предрешает ответа на второй. Более того, ускорение отдельного действия иногда лишь перемещает очередь на следующий участок. В таком случае локальная производительность растет, тогда как положение потребителя остается прежним.

Управление бизнес-процессами (business process management, BPM) позволяет поставить этот вопрос на уровне сквозной деятельности, а не отдельной функции. Обзоры (Putra и Mahendrawathi, 2024) и (Moreira и Dallavalle, 2025) подтверждают разнообразие связей BPM с цифровыми инновациями [1; 2]. Но перечисление организационных факторов не объясняет, на каком этапе цифровая возможность теряет связь с результатом. Именно этот объяснительный пробел составляет предмет статьи.

Отсюда возникает исследовательский вопрос: какие организационные механизмы обеспечивают переход от цифровых изменений к повышению результативности сквозного бизнес-процесса, при каких условиях этот переход нарушается и каким образом цифровизация сама влияет на развитие практик процессного управления?

Цель статьи заключается в разработке концептуального объяснения взаимосвязи цифровых преобразований и результативности бизнес-процессов с учетом организационных условий, определяющих характер и последствия технологических изменений. При этом процессная определенность, организационно-технологическая интеграция и управленческая обратная связь рассматриваются не как впервые выявленные факторы, а как взаимосвязанные элементы механизма формирования процессного результата.

Научный интерес представляет установление условий, при которых каждый из этих элементов способствует достижению ожидаемых изменений либо, напротив, ограничивает их. Такой подход позволяет перейти от констатации преимуществ цифровизации к объяснению причин, по которым повышение эффективности отдельных операций не всегда сопровождается улучшением результативности организации в целом.

Методология

Статья выполнена в формате критического концептуального обзора. В анализ включены восемь целенаправленно выбранных публикаций 2022–2026 гг.: два обзора взаимосвязи BPM и цифровых инноваций [1; 2], количественное исследование процессной культуры [3], отраслевая работа о зрелости [4], два исследования перепроектирования [5; 6] и две публикации о process mining [7; 8]. Такой состав дает возможность сопоставить различные объяснения и способы измерения, но не представляет собой исчерпывающую или статистически репрезентативную выборку литературы.

Для каждого исследования рассматривались четыре вопроса: что выступает объектом изменения; какой механизм предполагается; чем измеряется результат; какие выводы позволяет сделать исследовательский дизайн. В частности, различались нормативная модель и фактическое исполнение, результат отдельной операции и сквозного процесса, наблюдаемая связь и причинное объяснение. Полноценный протокол поиска по библиографическим базам, регистрация критериев исключения и метаанализ не проводились. Поэтому работа не именуется систематическим обзором, а сформулированные далее положения имеют статус гипотез.

Следовательно, граница доказательств проходит достаточно ясно. На основании выбранных публикаций можно уточнить возможные механизмы и обнаружить несоответствие между способами измерения; определить универсальную величину эффекта цифровизации или установить причинную зависимость нельзя. Именно поэтому далее

фактические результаты исследований отделены от интерпретаций, предлагаемых в настоящей работе.

Дискуссия

Бизнес-процесс - не только последовательность работ, изображенная на схеме. Он существует так же, как распределение прав принимать решения, обмен информацией, система исключений и ответственность за конечный результат. Дополнительная проверка может увеличивать продолжительность цикла, одновременно предотвращая дорогостоящую ошибку. Напротив, устранение формально лишнего шага может сократить время обработки, но повысить риск нарушения обязательных требований. Следовательно, количество действий не является самостоятельной мерой качества управления.

Разграничение понятий здесь имеет практический смысл. Оцифровка изменяет форму информации; автоматизация - способ выполнения действия; цифровизация процесса - организацию взаимосвязанных работ с использованием цифровых средств; цифровая трансформация затрагивает более широкий способ создания ценности. Это рабочие аналитические определения статьи, а не претензия на единую терминологию для всех научных школ. Их задача - не допустить, чтобы факт приобретения системы выдавался за изменение деятельности.

Представим электронное согласование договора. Если бумажный документ заменен цифровым, передача сведений становится быстрее и лучше прослеживается. Но когда сохраняются те же последовательные разрешения и дублирующие проверки, организационная конструкция почти не меняется. Иное дело - пересмотр полномочий, введение единого источника данных и устранение повторных решений. Технология в обоих случаях может быть одинаковой; различается управленческое вмешательство. Пример служит аналитической иллюстрацией и не является результатом авторского полевого исследования.

Начать следует с парадокса формализации. Чем лучше описаны границы процесса, ответственность и критерии результата, тем легче подготовить цифровое вмешательство. Но формализованный процесс может оставаться неэффективным. Если зрелость измеряют наличием регламентов, а успех цифровизации - их электронным исполнением, исследователь рискует принять сходство показателей за улучшение работы. Отраслевая методика (Курниковой и Егорова, 2025) [4] обращает внимание на специфику проектно-изыскательских процессов. Этот акцент принципиален: одинаковая степень регламентации не имеет одинаковой ценности для массовой операции и задачи, требующей экспертного суждения.

Стандартизация необходима там, где цена вариативности высока, а исключения редки. Но для деятельности, требующей профессионального суждения, чрезмерно жесткий маршрут может стать источником задержек. Из этого не следует призыв отказаться от правил. Более точный вывод состоит в необходимости согласовать степень формализации с характером задачи и риском ошибки. Вопрос о зрелости поэтому нельзя решать количеством инструкций: зрелой может быть и система, способная обоснованно отступать от стандартного сценария.

Насколько существенна культура процессного управления? Здесь полезно обратиться к количественным данным, а не ограничиваться нормативным тезисом о необходимости сотрудничества. (Distel, Plattfaut и Kregel, 2023) исследовали ответы 668 представителей муниципальных организаций Германии [3]. Связи отдельных компонентов культуры BPM со способностью к цифровым инновациям оказались неодинаковыми; часть отношений опосредовалась барьерами. Для настоящей статьи важно не только наличие статистических связей. Исследователи измеряли инновационную способность, а не совокупную стоимость или качество исполнения сквозного процесса. Переносить этот результат непосредственно

на экономическую эффективность коммерческого предприятия Казахстана нельзя: меняются и институциональная среда, и объект измерения.

С иной стороны ту же проблему обнаруживают исследования реинжиниринга. В работе (Хасеновой, Муратбекова и Абенова, 2025) BPMN используется для перепроектирования административных процессов [5]; (Rahmah и Suharso, 2026) приводят расчетное сокращение времени библиотечного обслуживания с 40,5 до 14,5 минуты в предложенной модели [6]. В обоих случаях речь идет о содержательных изменениях, но доказательства относятся к разным результатам. Новая схема показывает, как предполагается организовать работу; расчет времени характеризует один из ее параметров. Ни тот ни другой показатель не отвечает без дополнительных данных на вопрос, сколько ошибок возникает после внедрения, какова полная стоимость процесса и сохраняется ли эффект. Более того, проверка, которая выглядит лишней на схеме, иногда предотвращает дорогостоящий сбой. Ускорение следует считать улучшением только после оценки связанных с ним рисков.

Process mining добавляет к обсуждению фактические событийные данные. (Van der Aalst, 2022) показывает, как по журналам информационных систем можно реконструировать наблюдаемые траектории и обнаруживать отклонения [7]. Однако журнал фиксирует лишь то, что было зарегистрировано: переговоры, неформальные решения и причины исключений могут оставаться вне него. Поэтому нормативная модель BPMN и событийная аналитика не являются конкурентами. Первая позволяет обсуждать должный порядок действий, вторая - проверять наблюдаемое исполнение; обе требуют знания организационного контекста.

Самая трудная часть изменений начинается, пожалуй, после обнаружения отклонения. (Park и van der Aalst, 2022) связывают process mining с инициированием действий, развивая направление action-oriented process mining [8]. Однако рекомендации системы недостаточно, если руководитель процесса не вправе изменить порядок согласования или если устранение задержки повышает риск для другого подразделения. Диагностика отвечает на вопрос, что произошло; управленческое действие требует еще объяснить почему, выбрать допустимое вмешательство и проверить его последствия. Здесь технологии расширяют возможности BPM, но не заменяют ответственность за решение.

Центральное предположение статьи состоит в том, что между цифровой возможностью и процессным результатом существуют разные по природе разрывы, а именно:

Первый связан с процессной определенностью: организация не согласовала, что считать результатом и кто отвечает за него.

Второй возникает из-за ограниченной глубины изменения: ускорена операция, но сохранены прежние межфункциональные зависимости.

Третий относится к интеграции: системы обмениваются сведениями, тогда как правила и полномочия подразделений противоречат друг другу.

Четвертый обнаруживается после диагностики - когда данные не превращаются в решение с проверяемым эффектом.

Это не последовательные стадии, которые обязательно проходит каждый проект, и не универсальная шкала зрелости. Разрывы могут сочетаться, а один из них способен свести на нет пользу остальных изменений. Смысл такого разделения проявляется в пограничных ситуациях. Можно иметь подробную схему процесса, но не располагать достоверными данными о его реальном ходе. Можно объединить информационные системы, сохранив противоречивые требования подразделений. Можно своевременно обнаруживать задержки, но не дать владельцу процесса права изменить порядок согласования. Во всех трех случаях технологии работают; связь с конечным результатом нарушается по разным

причинам. Следовательно, объяснение должно искать не только степень цифровизации, но и конкретное место разрыва.

Такое объяснение отличается от классификации направлений цифровых инноваций у (Moreira и Dallavalle, 2025) [2] не перечнем факторов, а предметом вопроса: почему локальный технологический успех не становится сквозным результатом?

Исследование (Distel, et.al., 2023) [3] позволяет судить о связи культуры BPM с инновационной способностью; предложенная здесь рамка, напротив, требует отдельно измерять итог исполнения. При этом нельзя считать, что новая схема превосходит существующие модели по доказательной силе: ее преимущество пока лишь аналитическое, а не эмпирически установленное. Важно также отказаться от одностороннего представления, будто цифровизация всегда начинается после полного описания процесса. Нередко именно новая система впервые делает видимыми повторные согласования и неформальные маршруты. Тогда процессная определенность возникает в ходе цифрового проекта.

Таким образом, BPM может быть условием цифровизации, ее организационным механизмом и результатом последующих изменений. Направление связи следует устанавливать эмпирически, а не задавать заранее. Из этой конструкции можно вывести четыре гипотезы, допускающие опровержение. Связь процессной определенности с результативностью должна зависеть от вариативности задач: чрезмерная регламентация способна ослаблять положительный эффект. Влияние цифровых изменений на сквозной результат, вероятно, сильнее при одновременном согласовании систем и полномочий. Данные process mining должны приносить больший эффект там, где существует практика исполнения и проверки корректирующих решений. Наконец, процессная зрелость и цифровизация могут влиять друг на друга во времени, поэтому их взаимосвязь нельзя исследовать только в одном временном срезе. Ни одно из этих положений не следует принимать за доказанную закономерность.

Обсуждение

Как проверить предложенное объяснение так, чтобы не получить заранее ожидаемый ответ? Прежде всего нельзя использовать одни и те же признаки и для оценки предпосылок, и для оценки результата. Определенность полномочий, характер межфункциональных связей, полноту событийных данных и практику управленческого реагирования следует измерять отдельно от продолжительности полного цикла, частоты повторной работы, качества и совокупных затрат. Потребуются данные до и после внедрения, сопоставимые процессы и учет отраслевых различий. Желательно также проверить альтернативное объяснение: организации с лучшими результатами могут изначально обладать большими ресурсами и потому одновременно успешнее развивать BPM и внедрять технологии.

Для организаций практический смысл предложенного подхода состоит прежде всего в порядке постановки задачи. До выбора платформы следует определить конечного получателя результата, выявить межведомственные или межфункциональные согласования, проверить нормативную необходимость контрольных операций и зафиксировать исходные показатели. Затем нужно оценивать не только стоимость лицензий и скорость обработки, но и интеграцию данных, полномочия владельца процесса, стоимость сопровождения, качество и риск исключительных случаев. Это рекомендации, вытекающие из концепции; статья не содержит национальной выборки, позволяющей оценить распространенность соответствующих проблем в Казахстане. Предложенная рамка, однако, остается неполной. Восемь целенаправленно отобранных исследований не отражают всего спектра литературы, а различия их методов исключают количественное обобщение. Не проверено и то, насколько сильно каждый из четырех разрывов влияет на результат в зависимости от размера организации, отраслевого регулирования, компетенций сотрудников и

инвестиционных возможностей. Возможно, в отдельных процессах решающим окажется не согласование полномочий, а ограничение пропускной способности оборудования или нормативно установленный срок. Поэтому концепция предназначена прежде всего для постановки исследовательских вопросов и проектирования проверки, а не для готового прогноза отдачи от цифровизации.

Заключение

Техническая успешность и организационная результативность - разные характеристики цифровизации. Первая свидетельствует о работе решения, вторая - о том, изменилось ли создание ценности в сквозном процессе. Между ними находятся полномочия, согласованность подразделений, качество информации и способность принимать корректирующие решения. Их отсутствие объясняет, почему автоматизация может ускорить действие, но не изменить итог.

Таким образом, важнейший результат концептуального анализа - перенос внимания с количества внедренных технологий на организационный механизм получения ценности. BPM может предшествовать цифровизации, обеспечивать ее проведение и одновременно изменяться под влиянием новых данных. Для проверки этой взаимосвязи нужны исследования с независимыми показателями условий и результатов. До появления таких данных корректнее говорить не о доказанной эффективности четырех элементов, а об объяснительной модели, позволяющей точнее поставить практический вопрос: где именно теряется эффект цифрового проекта, и кто способен устранить этот разрыв?

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INSTITUTIONAL MODELS FOR THE DEVELOPMENT OF SOCIAL ENTREPRENEURSHIP: THEORETICAL FOUNDATIONS AND INTERNATIONAL EXPERIENCE

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Abstract. This article examines the institutional prerequisites for the emergence and development of social entrepreneurship and the distinctive features of institutional models established in different national contexts. The aim of the study is to systematize theoretical approaches to explaining the institutional diversity of social enterprises and to identify directions for adapting international experience to the conditions of Kazakhstan. The methodological framework comprises comparative institutional analysis, the typological classification of organizational models, and a critical review of academic literature and the legal and regulatory framework. The study demonstrates that the sustainability of social enterprises depends not on individual incentives or formal legal status alone, but on the coherence of legal regulation, financial mechanisms, social norms, and patterns of interaction among the state, businesses, and civil society. An analytical framework for assessing the institutional environment is proposed, integrating legal, resource-related, organizational, and societal components. The study identifies directions for improving the institutional conditions for social entrepreneurship in Kazakhstan. The findings represent a theoretical and analytical synthesis and do not claim to provide empirical validation of causal relationships.

Keywords: social entrepreneurship; institutional model; social enterprise; institutions; social economy; international experience; government support; Kazakhstan.

Introduction

Social entrepreneurship has gained a distinctive position in discussions on approaches to addressing societal challenges, as it combines entrepreneurial initiative with a sustained commitment to creating social value. Unlike traditional philanthropy, a social enterprise seeks to establish a recurring source of revenue and develop structured management processes. At the same time, unlike conventional commercial businesses, its performance cannot be fully assessed in terms of sales volume and profit alone. This dual nature makes social entrepreneurship particularly sensitive to the institutional environment, ranging from profit distribution rules to the recognition of socially significant outcomes.

There is no universally applicable model of a social enterprise. In some countries, social entrepreneurship has emerged from cooperative movements and traditions of mutual assistance; in others, it has evolved from the nonprofit sector, which gradually adopted entrepreneurial

approaches; while in still others, it has developed from private business initiatives with an explicit social mission. Consequently, simply adopting a foreign legal form rarely makes it possible to replicate its practical advantages. Instead, it is necessary to examine the conditions under which a particular organizational form emerged and continues to operate.

In Kazakhstan, the relevance of this issue is associated with the establishment of a specific legal framework for social entrepreneurship. The incorporation of relevant provisions into the Entrepreneurial Code has provided institutional recognition of the sector. However, legal recognition alone does not guarantee organizational sustainability. Equally important are the quality of access to financing, opportunities for market entry, managerial competencies, interaction with local communities, and the clarity of criteria used to assess social performance [6].

The aim of this article is to synthesize the theoretical foundations of the institutional approach and conduct a comparative analysis of international models of social entrepreneurship in order to identify relevant directions for their application in Kazakhstan. To achieve this aim, the study addresses the following objectives: examining the role of formal and informal institutions; comparing the main models of social enterprises; identifying the limitations of mechanically transferring foreign institutional arrangements; and proposing a coherent framework for institutional development. The study is conceptual in nature and is based on published academic literature and an analysis of legislation.

Theoretical Foundations of Institutional Analysis of Social Entrepreneurship

The institutional approach explains entrepreneurial behavior not only through individual capabilities and available resources but also through established rules, expectations, and practices within which economic decisions are made. For social entrepreneurship, the interaction between formal institutions, including legislation, legal status, taxation regimes, and procurement procedures, and informal institutions, such as trust, a culture of solidarity, societal perceptions of corporate responsibility, and traditions of collective action, is particularly important.

In his work, J. Kerlin proposes examining differences among national models through historically established combinations of institutional factors. This leads to an important methodological implication: the definition of a social enterprise cannot be entirely separated from the societal context in which it is applied. An organizational and legal form reflects a particular history of relationships among the state, the market, and the nonprofit sector rather than representing a neutral institutional arrangement that operates identically across countries [1].

The debate surrounding "institutional voids" is of particular interest. According to one perspective, insufficient provision of public services creates opportunities for social initiatives. However, the absence of institutional support simultaneously increases their costs and limits their potential for expansion. A study by U. Stephan, L. Uhlaner, and C. Stride, based on data from 26 countries, highlights the importance of the interaction between formal and informal institutions, as well as resource support, in fostering engagement in social entrepreneurship [2]. Therefore, the existence of a social need should be distinguished from the presence of conditions that enable a sustainable entrepreneurial response to that need.

From an institutional perspective, it is useful to distinguish three interconnected levels. At the macro level, legislative frameworks, social policies, and broader cultural norms are established. At the meso level, support institutions operate, including financial intermediaries, support infrastructure organizations, business associations, universities, and local partnership networks. At the micro level, managerial decisions within individual enterprises become evident, including ownership structures, mechanisms for stakeholder participation, income distribution, and performance evaluation. A lack of coordination between even two of these levels can undermine the effectiveness of measures that may otherwise appear justified when considered individually.

International Institutional Models: A Framework for Comparison

Comparative academic literature identifies several established organizational models that cannot be fully explained by geographical distinctions alone. J. Defourny and M. Nyssens propose a typology encompassing entrepreneurial nonprofit organizations, social cooperatives, social businesses, and organizations emerging from public-sector activities [3]. This classification is valuable because it enables researchers to examine not only the legal structure of an enterprise but also the origins of its resources, governance mechanisms, and the nature of its social commitments.

The cooperative model is based on stakeholder participation in collective governance. Its potential stems from the fact that its social objectives often directly reflect the interests of its members, including employees, service users, and local communities. However, democratic governance does not automatically guarantee financial performance: decision-making processes may be slower, while limited access to capital requires additional investment mechanisms. A key strength of the cooperative model lies in its ability to embed social objectives into ownership structures and rules governing the distribution of organizational outcomes.

The social business model is closer to conventional entrepreneurship in terms of operational organization, customer acquisition, and cost management. Its distinguishing feature is the prioritization of a measurable social problem that the enterprise seeks to address through market-based offerings. When comparing such organizations, it is important to consider the extent to which their social objectives are protected from being displaced by investors' interests, how profits are distributed, and whether mechanisms of public accountability exist. The central issue is therefore not the opposition between profit and mission but the effectiveness of their institutional alignment.

A comparison of European and American experiences conducted by J. Defourny and M. Nyssens demonstrates that national approaches to social entrepreneurship differ in the importance assigned to collective governance, market-generated revenue, social innovation, and individual entrepreneurial initiative [4]. European traditions are more frequently discussed in relation to the social economy, cooperatives, and stakeholder participation, whereas American academic discourse places considerable emphasis on entrepreneurial initiative and business-oriented approaches. However, this generalization does not eliminate the internal diversity of either system and should not be interpreted as a rigid division of countries into two fixed models.

Institutional Configuration as a Factor in the Sustainability of Social Enterprises

International experience suggests that the performance of social entrepreneurship depends less on the choice of a particular organizational and legal form than on the compatibility of different elements of the institutional environment. A well-developed legal framework without effective financial intermediaries does not ensure access to investment resources. Accessible financing without competent management does not guarantee service quality. Strong societal demand for social solutions, combined with low levels of trust among stakeholders, increases transaction costs.

On this basis, the study proposes examining an institutional model as a combination of four components. The first is the legal and regulatory component, encompassing the conditions for recognizing social enterprise status, applicable restrictions and obligations, and transparent eligibility criteria for support measures. The second is the resource and economic component, which includes access to credit, investment, procurement opportunities, consulting services, and infrastructure. The third is the organizational and managerial component, covering decision-making mechanisms, managerial competencies, and the assessment of social and financial

performance. The fourth is the sociocultural component, incorporating trust, willingness to cooperate, public recognition, and local community engagement.

The proposed classification is analytical in nature. In practice, these components are not independent. For example, transparent reporting strengthens trust, trust facilitates access to partnership-based resources, and adequate resources enable enterprises to demonstrate sustainable performance. Conversely, complex requirements for confirming social enterprise status, short-term financing, and limited managerial capabilities may create a negative chain of effects in which the social mission becomes a source of additional obligations unsupported by sufficient resources.

A managerial assessment of such an institutional configuration requires caution. The number of registered social enterprises reflects the institutional recognition of the sector but does not reveal its economic sustainability. Revenue indicates market activity but does not demonstrate social impact. Similarly, the number of service beneficiaries cannot automatically be equated with improvements in their quality of life. An accurate assessment therefore requires a comprehensive set of indicators, including financial sustainability, employment stability, target group coverage, service accessibility, and verified improvements in socially significant outcomes.

Opportunities for Adapting International Experience to Kazakhstan

For Kazakhstan, a fundamentally important priority is to move beyond viewing social enterprises primarily as recipients of government support and toward recognizing them as independent participants in economic relations. The existing provisions of the Entrepreneurial Code define social entrepreneurship in terms of addressing social problems and provide for the inclusion of eligible entities in the relevant register [6]. This establishes a formal institutional framework for the sector and enables the development of targeted support mechanisms. However, further development of the institutional environment requires aligning this framework with market needs and regional characteristics.

The first direction concerns the predictability of regulatory requirements. Social enterprises need to understand in advance the conditions for obtaining and maintaining their status, the procedures for demonstrating their social orientation, and the practical implications of being included in the register. The more transparent these rules are, the lower the administrative uncertainty faced by small organizations. At the same time, formal criteria should reflect the substantive characteristics of enterprise activities, since identical quantitative indicators may not be equally appropriate for organizations engaged in employment integration, social service provision, or environmental solutions.

The second direction involves expanding opportunities for market participation. Subsidies and grants can help address the challenges of establishing an enterprise; however, long-term sustainability generally requires a stable customer base and diversified revenue streams. Facilitating participation in procurement procedures, developing partnerships with companies, and increasing the market visibility of products and services can reduce dependence on one-off support programs. Clear quality requirements and contractual payment terms are particularly important, as cash flow gaps may pose a greater challenge for small social enterprises than the nominal amount of financial support available.

Discussion of Results

Consequently, academic comparisons should consider not only the formal organizational structure of social enterprises but also the historical sequence through which their social and economic mechanisms have emerged. Within the historical-institutional framework proposed by Kerlin, identical legal instruments may produce different outcomes because they are embedded in distinct systems of expectations, resources, and stakeholder interactions [1]. This consideration is particularly important when developing public policies based on international models.

The proposed four-component analytical framework, comprising legal and regulatory, resource and economic, organizational and managerial, and sociocultural dimensions, systematizes these interdependencies and provides a basis for subsequent empirical validation. Such research could compare regions in terms of access to procurement opportunities, availability of advisory support programs, partnership networks, and the actual sustainability of social enterprises. However, without primary empirical data, it is not possible to establish that any particular factor exerts a statistically significant or determining influence. The present article is therefore limited to providing a theoretical justification for future research directions. A more recent study examining the role of institutional hierarchy also emphasizes the need to reconsider simplified assumptions regarding institutional voids and support mechanisms [5].

Conclusion

The theoretical analysis conducted in this study confirms the need to consider social entrepreneurship as an institutionally embedded form of economic activity in which commercial methods are employed to achieve socially significant objectives. Differences among national models emerge under the influence of historical conditions, the structure of government social obligations, traditions of the nonprofit sector, characteristics of financial markets, and prevailing societal norms.

The systematization of international experience has made it possible to identify four organizational models: the entrepreneurial nonprofit model, the cooperative model, the social business model, and the public-sector-related model. None of these can be regarded as universally preferable.

Their advantages become evident when legal frameworks, financing mechanisms, management practices, and societal expectations are effectively aligned.

For Kazakhstan, priority should be given not to the mechanical adoption of foreign legal frameworks but to the development of a coherent institutional environment. Key priorities include ensuring regulatory predictability, expanding market access, diversifying financial instruments, strengthening regional partnerships, and developing a proportionate system for assessing social performance. The proposed four-component analytical framework can serve as a foundation for further comparative and empirical research. Such research should aim to identify which combinations of institutional conditions are most strongly associated with the sustainability of social enterprises and the effectiveness of their efforts to address social problems.

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THE ROLE OF MARKETING STRATEGIES IN ENHANCING THE COMPETITIVENESS OF PRODUCTS AND SERVICES OF SOCIAL ENTERPRISES

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Abstract. This article examines the role of marketing strategies in developing competitive advantages for the products and services offered by social enterprises. The relevance of the study stems from the need to reconcile market sustainability with the pursuit of socially significant objectives amid limited financial, human, and organizational resources. The methodological framework is based on comparative analysis, the systematization of findings from international studies, and conceptual modeling. The study explores the specific features of social enterprises' value propositions, consumer segmentation, positioning, pricing, marketing communications, and distribution channels. It demonstrates that marketing performance cannot be reduced to sales growth alone; rather, it should be assessed in terms of product accessibility for target groups, consumer trust, and verifiable social impact. The article proposes an original conceptual model of competitiveness development that integrates market orientation, marketing competencies, perceived value, and the dual performance of social enterprises. Recommendations are formulated for adapting marketing strategies to the evolving conditions of social entrepreneurship in Kazakhstan. The study is theoretical and analytical in nature, and its findings require further empirical validation.

Keywords: social entrepreneurship; social enterprise; marketing strategy; competitiveness; market orientation; value proposition; social value; marketing competencies.

Introduction

Social entrepreneurship occupies a distinctive position in the modern economy, as it combines the production of goods and provision of services with the pursuit of solutions to social problems. A social enterprise seeks to generate sufficient revenue to sustain its operations; however, market success is not its sole objective. Unlike a conventional commercial organization, it takes into account the needs of population groups that often face difficulties in accessing quality products, employment opportunities, and essential services. This combination of objectives creates a distinctive competitive environment: offering an affordable price or communicating a charitable mission is not sufficient. Products and services must meet actual market demand, while their social orientation must be clearly communicated and supported by verifiable evidence. In international academic literature, marketing in social enterprises is examined as a distinct field of research. In their systematic review, C. Bandyopadhyay and S. Ray demonstrate that the marketing activities of such organizations are complicated by the need to address the expectations of multiple stakeholders under resource constraints [1]. Research conducted by G. Liu, T.-Y. Eng, and S. Takeda

in the United Kingdom and Japan indicates that not all marketing capabilities are equally associated with organizational performance; enterprises need to develop and prioritize capabilities that align with their specific objectives [2]. These findings highlight the importance of moving beyond fragmented marketing activities toward a coherent strategic system.

The aim of this article is to substantiate the role of marketing strategies in enhancing the competitiveness of products and services offered by social enterprises and to propose a framework for their practical application. To achieve this aim, the following objectives are addressed: clarifying the concept of competitiveness in relation to social enterprises' products and services; comparing findings from international studies; identifying key strategic marketing tools; developing an original conceptual model; and outlining strategic priorities for social enterprises in Kazakhstan. The object of the research is the marketing activities of social enterprises, while the subject is the organizational and economic relationships between marketing strategies, competitive advantages, and social outcomes.

Materials and Methods

The study is based on a qualitative analysis of six peer-reviewed international publications addressing marketing approaches, market orientation, marketing capabilities, and social value creation. The sources were selected based on their direct relevance to the research problem and their suitability for comparing different national contexts. The study does not include an original survey, a statistical sample, or an econometric assessment; its conclusions are derived from a theoretical synthesis of existing scientific evidence. The research employs comparative analysis to identify similarities and differences between commercial and social enterprise marketing approaches; logical systematization to distinguish the stages involved in developing competitive advantages; and conceptual modeling to construct a cause-and-effect framework. The competitiveness of a social enterprise's products and services is defined as the ability of its offering to remain preferable to available alternatives for target consumers while simultaneously ensuring economic viability and adherence to its stated social mission. This definition represents the authors' own analytical interpretation and is applied throughout the subsequent discussion.

Theoretical Approaches to Marketing in Social Enterprises

For a conventional commercial organization, market orientation involves systematically studying consumer needs, assessing competitors, and coordinating activities across organizational departments. A social enterprise operates within a more complex system of relationships. Customers, beneficiaries of social assistance, partners, donors, and government institutions may have different perceptions of organizational effectiveness. For example, a customer may expect convenience and service quality, while a social partner may evaluate the accessibility of that service to a vulnerable population group. A marketing strategy must reconcile these expectations without reducing the social mission to a merely declarative advertising message.

L. da Silva Nascimento et al. propose distinguishing among commercial, social, and societal approaches to strategic marketing in social enterprises [3]. The commercial approach focuses on market exchange, customer satisfaction, and market sustainability. The social approach emphasizes behavioral change and solutions to specific social problems. The societal approach extends the analysis to the broader implications of enterprise activities for communities and societal institutions. These approaches should not be regarded as mutually exclusive; their relative importance depends on the nature of the social problem, the target groups, and the enterprise's revenue model. In a study based on data from 164 social enterprises in the United Kingdom, C. R. Bhattarai, C. C. Y. Kwong, and M. Tasavori identify a positive relationship between market orientation and both economic and social performance [4]. However, the capability to significantly reshape market rules was primarily associated with economic performance. This finding has important methodological implications: innovation and increased market share do not

automatically lead to improved social performance. Therefore, the assessment of competitive advantages should examine economic and social outcomes separately.

Marketing Strategies as a Source of Competitive Advantages

The first strategic direction involves market segmentation and target audience selection. For a social enterprise, it is advisable to distinguish between at least two groups: customers who pay for a product or service and direct beneficiaries of the social impact generated. In some cases, these groups overlap, for example, when affordable educational services are provided to a specific target audience. In other cases, customers purchase products, while social outcomes are achieved through the employment of workers or the allocation of part of the revenue to addressing a social problem. Failure to distinguish between these groups leads to unclear positioning and ineffective marketing communications. The second strategic direction concerns product strategy and quality management. The competitiveness of a social enterprise's products does not arise merely from their production by a socially oriented organization but rather from a combination of consumer-oriented characteristics, consistent quality, and a well-substantiated additional value proposition. For physical products, this involves monitoring product specifications and packaging, providing clear information about composition and intended use, and responding to customer feedback. For services, essential factors include convenient booking procedures, accessible service locations, timely service delivery, and the professional competence of employees. Expanding the product range is justified only when it responds to verified market demand rather than an intention to produce as many product varieties as possible.

The third strategic direction involves pricing strategy. Social enterprises must consider production costs and the need for financial sustainability alongside consumers' purchasing power. A universal price reduction may stimulate short-term demand but simultaneously deprive an organization of the resources necessary to fulfill its social mission. More appropriate approaches include differentiated pricing, combining commercial and subsidized offerings, establishing long-term contracts, and transparently communicating the cost structure. However, preferential pricing arrangements require adequate financial support: without calculating cost coverage and identifying sources of compensation, affordability becomes unsustainable.

The fourth strategic direction is a communication strategy based on credibility. A social mission can potentially strengthen consumer trust, but excessively emotional advertising unsupported by verifiable results creates reputational risks. Therefore, marketing communications should provide clear product information and carefully formulated, verifiable claims regarding social benefits. Instead of making abstract promises to "change lives," enterprises should communicate specific information, including whom the service is intended for, how accessibility is ensured, and which product characteristics have been verified. Customer recommendations and partnership success stories can also be useful, provided that confidentiality is maintained and participants give their voluntary consent.

International Experience: A Comparative Analysis of Research Findings

The experience of the United Kingdom and Japan examined by G. Liu, T.-Y. Eng, and S. Takeda demonstrates that marketing capabilities should be developed selectively [2]. Some organizations primarily require systematic needs assessment, while others need to improve their distribution channels or sales management. A standardized set of marketing activities applied uniformly to all social enterprises fails to account for differences in revenue models, target audiences, and stages of organizational development. This leads to an important practical implication: before investing in advertising and promotion, social enterprises should identify and assess the main constraints affecting their competitiveness.

A study of Mexican social enterprises conducted by J. Cavazos-Arroyo and R. Puente-Diaz, based on responses from 118 managers, identified a relationship between marketing capabilities, social innovation, and social value creation [5]. However, within the model examined, the authors did not find evidence supporting a direct positive relationship between social innovation and economic value. Consequently, it would be incorrect to assume that every socially oriented innovation necessarily increases revenue. Marketing decisions should therefore be evaluated in terms of both their social benefits and their capacity to generate demand and sustain organizational operations [6].

Proposed Conceptual Model for Assessing the Impact of Marketing Strategies on Competitiveness

Based on the theoretical approaches reviewed, the study proposes an original sequential conceptual model: Assessment of consumer needs and competitors → Development of a differentiated value proposition → Alignment of product, pricing, communication, and distribution policies → Enhancement of perceived value and consumer trust → Strengthening of competitive positions → Evaluation of economic and social outcomes. This model represents an analytical hypothesis and should not be interpreted as an empirically established causal relationship.

For practical assessment, four groups of indicators are proposed. The market-related group includes repeat purchases, customer retention, the proportion of successfully fulfilled orders, and changes in revenue by product category. The product-related group reflects satisfaction with quality, the frequency of customer complaints, service accessibility, and the extent to which the offering meets the needs of the selected market segment. The marketing-related group covers customer acquisition costs, channel effectiveness, inquiry-to-customer conversion rates, and brand awareness, provided that appropriate measurement methods are available. The social performance group characterizes the coverage of target populations, product accessibility for their members, and verified changes associated with the organization's social mission.

Opportunities for Application in Kazakhstan

The introduction of regular marketing audits appears to be a promising approach. At the first stage, an enterprise can identify its main customer groups and social beneficiaries. At the second stage, it can compare its offering with available market alternatives in terms of accessibility, quality, and price. At the third stage, it can select two or three priority areas for improvement. At the fourth stage, it can assess changes using predetermined indicators. This approach does not require extensive research infrastructure and contributes to greater transparency in marketing decision-making.

Furthermore, future research in Kazakhstan requires empirical data. A promising direction would be to compare social enterprises according to industry, region, years of operation, and revenue model, while measuring the presence of marketing planning, the structure of marketing channels, repeat sales, and social performance indicators. The proposed model could be tested through interviews, surveys, and longitudinal analysis of economic data. Only after such empirical validation will it be possible to draw well-founded conclusions about which combinations of marketing tools generate sustainable competitive advantages under Kazakhstan's specific conditions.

Discussion of Results

The analysis provides a clearer understanding of the role of marketing within the management system of a social enterprise. Marketing should not be regarded as a peripheral function concerned exclusively with advertising. Rather, through the identification of consumer needs and the development of value propositions, marketing decisions influence product characteristics,

service delivery, revenue structures, and the sustainability of social outcomes. This interpretation is consistent with research findings emphasizing the need for selective development of marketing capabilities [2] and the relationship between market orientation and the dual economic and social performance of social enterprises [4].

Conclusion

Marketing strategies represent one of the key mechanisms for enhancing the competitiveness of products and services offered by social enterprises. Their significance lies in their ability to identify the actual needs of target audiences, improve the quality of value propositions, strengthen consumer trust, and establish an economic foundation for sustaining the social mission. However, the status of a social enterprise does not in itself guarantee a competitive advantage. Sustainable market demand is primarily generated through a combination of reliable products, well-justified pricing, convenient accessibility, and effective marketing communications.

The analysis of international research has demonstrated that there is no universally applicable combination of marketing capabilities. Market orientation may be positively associated with both economic and social outcomes; however, individual innovations and communication strategies may produce varying effects. Therefore, the selection of marketing strategies should be selective and tailored to the specific constraints of an enterprise, its target market segments, and its model of social value creation.

The proposed conceptual model integrates needs assessment, the coordination of marketing instruments, the development of perceived value, and the evaluation of dual economic and social performance. For social enterprises in Kazakhstan, promising strategic directions include regular market demand analysis, quality improvement, the development of partnership-based distribution channels, and the use of verifiable social performance indicators. Future research should focus on empirically assessing the impact of individual marketing instruments on competitiveness, taking into account industry-specific and regional differences.

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FINTECH-ENABLED FINANCIAL LEASING IN AZERBAIJAN: DIGITAL CREDIT ASSESSMENT, RISK MANAGEMENT AND REGULATORY REFORM

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Abstract. Financial leasing can give Azerbaijani enterprises access to productive assets without requiring the full acquisition price at the outset. Digital identification, transactional information and automated payment monitoring may improve this instrument, but they do not eliminate borrower, asset or operational risks. This article evaluates fintech-enabled leasing through the existing legal framework, official credit statistics and evidence on alternative-data underwriting. Attention is given to the financial leasing law adopted in 2026, whose provisions were not yet effective in October 2026.
Keywords: financial leasing; fintech; Azerbaijan; asset finance; digital underwriting; credit risk; regulation.

AZƏRBAYCANDA FİNTEKS ƏSASLI MALİYYƏ LİZİNQİ: RƏQƏMSAL KREDİT QİYMƏTLƏNDİRİLMƏSİ, RİSKLƏRİN İDARƏ EDİLMƏSİ VƏ HÜQUQİ İSLAHATLAR

Xülasə. Maliyyə lizinqi Azərbaycan müəssisələrinə aktivin tam alış dəyərini əvvəlcədən ödəmədən istehsal vasitələrindən istifadə imkanı yaradır. Rəqəmsal identifikasiya, əməliyyat məlumatları və avtomatlaşdırılmış ödəniş nəzarəti bu alətin tətbiqini asanlaşdıra bilər. Bununla belə, borcalan, aktiv və əməliyyat riskləri qalır. Məqalədə finteks əsaslı lizinqin hüquqi və iqtisadi xüsusiyyətləri rəsmi kredit statistikası və rəqəmsal qiymətləndirmə təcrübəsi ilə əlaqələndirilir. 2026-cı ildə qəbul olunmuş, lakin oktyabr ayına qədər qüvvəyə minməmiş yeni qanunun tətbiq perspektivləri də qiymətləndirilir.
Açar sözlər: maliyyə lizinqi; fintex; Azərbaycan; aktivlərin maliyyələşdirilməsi; rəqəmsal qiymətləndirmə; kredit riski; tənzimləmə.

ФИНАНСОВЫЙ ЛИЗИНГ НА ОСНОВЕ ФИНТЕХ-ТЕХНОЛОГИЙ В АЗЕРБАЙДЖАНЕ: ЦИФРОВАЯ ОЦЕНКА КРЕДИТОСПОСОБНОСТИ, УПРАВЛЕНИЕ РИСКАМИ И ПРАВОВАЯ РЕФОРМА

Аннотация. Финансовый лизинг позволяет предприятиям Азербайджана использовать производственные активы без единовременной оплаты полной стоимости их приобретения. Цифровая идентификация, данные о транзакциях и автоматизированный контроль платежей способны повысить удобство этого инструмента, однако не устраняют кредитные, имущественные и операционные риски. Рассматриваются экономические особенности финтех-лизинга, действовавшее законодательство и практические возможности цифровой оценки заемщиков. Отдельное внимание уделено принятому в 2026 году закону о финансовой аренде, основные положения которого в октябре еще не вступили в силу.
Ключевые слова: финансовый лизинг; финтех; Азербайджан; финансирование активов; цифровой скоринг; кредитный риск; регулирование.

INTRODUCTION

A small firm can operate profitably and still be unable to purchase the equipment required for a new contract. The difficulty often concerns the timing of financing rather than the commercial usefulness of the asset. Financial leasing addresses this mismatch by allowing the business to use an asset while paying for it over an agreed period. In Azerbaijan, the instrument is relevant to enterprises that rely on vehicles, manufacturing machinery, agricultural equipment and other identifiable fixed assets. Its development also raises questions about ownership, contract enforcement, risk allocation and the cost of capital. Digital finance can simplify these processes, but its value depends on how the technology changes the quality and expense of the underlying transaction, rather than on the digital character of the application itself.

Fintech-enabled leasing combines a traditional contractual structure with digital elements such as remote identity verification, electronic document processing, access to credit information and automated collection. In a well-designed process, the client may submit an application remotely, the provider can check the proposed asset and supplier, and installments can be adjusted to the expected operating cash flow. The economic substance remains asset finance. A digital portal does not transform leasing into an unsecured consumer loan, and a payment application does not establish that the applicant can service an obligation. The contractual relation among lessor, lessee and supplier continues to determine responsibilities when equipment is defective, payments are late or the asset loses value.

Azerbaijan's changing legal environment gives these issues immediate importance. The Law on Financial Leasing (No. 412-VIIQ of 26 May 2026) was published on 25 June 2026 and was scheduled to take effect six months after publication, on 25 December 2026. Consequently, as of October 2026 it is not correct to describe all of the new registration and supervision requirements as provisions already in force [2, Arts. 15, 24–25]. Distinguishing adopted rules from effective rules is essential for interpreting the actual obligations of a leasing business, particularly where a digital provider is planning new products during the transition period.

The assessment draws on Azerbaijan's Civil Code, the new legislation and Central Bank financial statistics, together with publicly available research on digital credit evaluation. It does not present internal transaction records, client-level defaults or financial statements for a named private leasing company, because such firm-specific evidence has not been made available. Instead, it examines the operational decisions and risks that can be supported by the verified sources. The result is a case-oriented assessment of fintech leasing as a financing model in Azerbaijan, rather than an invented performance study of a particular company.

MAIN PART

The legal identity of a leasing transaction is a useful starting point. Under Chapter 38 of Azerbaijan's Civil Code, as reflected in the Central Bank's published English version, a lessor is obliged to make specified property available for use in exchange for payments and under agreed contractual conditions. The provisions distinguish the lessor, lessee and seller or supplier, and address the acquisition and use of the object [1, pp. 226–228]. That tripartite structure differs from the disbursement of a general-purpose loan. The lessor's exposure includes not only the client's willingness and ability to pay but also the cost, authenticity, condition and recoverability of a physical asset. A digital customer interface can improve the administration of these duties, yet it cannot replace their substance.

The 2026 Law on Financial Leasing develops a more explicit framework for the sector. Its definition of a financial lease includes arrangements where an asset may transfer to the lessee at the end of the term, where the lease term exceeds 75% of the asset's useful life, where residual value falls below 20% of initial market value, or where cumulative payments meet at least 90% of the initial market value [2, Art. 1.1.3]. These are alternative statutory criteria within the adopted law; they are not evidence that all contracts in the existing market followed the same structure.

For an enterprise, the classification matters because an agreement described commercially as a lease may have distinct tax, accounting and ownership consequences, depending on its contractual terms and the legislation then in force.

Effective implementation will also change the position of leasing providers. Article 15 of the 2026 law provides for Central Bank oversight, an official register for eligible lessors, risk management requirements and the submission of relevant information to credit reporting systems. The act specifies a nine-month transition period after its commencement for existing leasing businesses to align their operations with the new framework [2, Arts. 15, 24–25]. These requirements were prospective in October 2026. It would therefore be inaccurate to evaluate a provider's 2025 performance against a registration obligation that had not yet entered into force. The important policy issue is whether the new supervisory arrangements can improve information quality and contractual reliability without creating disproportionate administrative costs for smaller providers.

Leasing differs from a conventional business loan most visibly in the connection between the financing agreement and the asset. A bank may take collateral over property owned by the borrower, while a leasing provider acquires or controls the financed item under the lease structure. Asset ownership can reduce some recovery obstacles, but it does not remove the economic costs of repossession, repair, storage and resale. A specialized machine may have a high acquisition price and little secondary-market demand. A vehicle can be easy to identify but subject to high usage, maintenance and accident risks. The appropriate down payment, term and residual value depend on these characteristics, as well as on the borrower's capacity to generate revenue from the asset.

Table 1. Functional differences between business lending and fintech-enabled leasing

Financing dimension	Conventional business loan	Fintech-enabled financial lease
Primary purpose	General or asset-specific business borrowing	Financing the use of an identified productive asset
Initial verification	Borrower, income and collateral information	Borrower, supplier, asset condition and title
Payment design	Installments under loan contract	Lease payments linked to asset and cash flow
Main recovery concern	Borrower default and collateral enforcement	Default plus asset repossession and resale value
Digital contribution	Application, scoring and payment processing	Same functions plus asset verification and monitoring

Source: Analytical comparison based on Azerbaijan's Civil Code (Chapter 38), the 2026 Law on Financial Leasing and CGAP (2024). This is not a survey or a measured performance table.

The comparison demonstrates that the economic evaluation of leasing cannot be confined to a nominal annual financing rate. The relevant measure includes the down payment, all periodic installments, fees, insurance, taxes where applicable, maintenance responsibilities and any final transfer price. It should also reflect the timing of those payments. If a business receives most of its income after harvest, fixed monthly installments may create avoidable liquidity pressure even if the asset is profitable over the full year. Conversely, weekly installments may be suitable for a frequently used commercial vehicle with steady verified receipts. Payment scheduling should therefore be linked to the enterprise's cash conversion cycle, not chosen primarily for convenience of automated collection.

The capacity of digital assessment is often explained through the difference between a credit record and a transaction record. A credit report describes past borrowing behavior, including repayments and arrears. Transaction records can provide evidence of current commercial activity, such as incoming customer payments, supplier charges, invoice settlement and operating costs. When appropriately validated, the combination may help a lender understand a firm whose formal

credit history is limited. Nevertheless, recorded sales are not identical to free cash flow. Rent, fuel, employee pay, taxes and irregular purchases must be considered before deciding what installment is affordable. A data-driven score that predicts whether an applicant has frequent receipts but ignores their costs can overestimate repayment capacity.

International evidence supports the value of careful data combination while also showing why local validation is necessary. A CGAP study of two Indian fintech providers, Fundfina and KarmaLife, found that transactional information offered meaningful predictive value and that combining it with credit history improved model performance in the examined borrower groups [5, pp. 1–3]. The study covers retail microenterprises and platform workers in India, not financial leasing clients in Azerbaijan. The application to leasing is therefore conceptual: verified business transactions could help estimate the capacity to service an asset-finance contract, but predictive accuracy would need to be measured against actual local lease arrears, recoveries and losses.

Research on fintech lending provides an additional warning against assuming that technology eliminates information risk. Using loans originated through two United States fintech platforms before the pandemic, Cornelli, Frost, Gambacorta and Jagtiani found that platform assessments could identify creditworthiness more effectively than conventional scoring measures in the observed populations [6, pp. 1–5]. These results are not a performance estimate for Azerbaijan. Leasing introduces a second source of information not present in a general-purpose small-business loan: the market value and operational usefulness of the financed asset. A robust decision should therefore combine borrower cash-flow assessment with supplier due diligence, asset valuation, verification of title and a practical recovery scenario.

The current financial structure of Azerbaijan gives context to the potential scale of digital leasing. By end-2025, banks held a loan portfolio of roughly AZN 30.1 billion, of which 53.6% consisted of business loans. Non-bank credit institutions had a reported loan portfolio of about AZN 1.05 billion within the Central Bank's specified analytical perimeter; business loans accounted for approximately AZN 265.6 million [3, pp. 13–14, 47–48]. These are not statistics on leasing contracts, and no national digital-leasing market share can be derived from them. They show that lending to businesses is established in the financial system, while specialized asset-based providers would need to develop their own funding, underwriting and reporting capacity.

Portfolio quality is central to that development. In 2025, the Central Bank reported a 10.4% non-performing-loan ratio for non-bank credit institutions and 6.1% for their business-credit segment [3, p. 48]. These figures refer to institutions and loans covered by that report, not to the leasing sector as a separate portfolio. Nevertheless, they establish why a new provider should monitor arrears by contract vintage, asset type and customer segment rather than rely on disbursement growth alone. A lease with temporarily delayed payment and a recoverable asset differs from one where the underlying business has ceased operations and the equipment has little resale value. A meaningful risk review combines borrower delinquency with expected loss after possible asset recovery.

Digital processing introduces operational risks of its own. Identity fraud may arise when an applicant presents false documents or obtains finance for an asset controlled by another person. Supplier fraud may involve inflated purchase prices, fabricated delivery or duplicate invoicing. Data errors can lead to incorrect credit decisions; automated messages or payment transfers may fail during system outages. A leasing platform therefore requires independent confirmation of the supplier and asset, secure storage of agreements, separation of approval authority and regular reconciliation between supplier payment, asset delivery and the lease ledger. These controls are not incidental administrative overhead. They preserve the integrity of the asset and the contract that constitute the lessor's economic protection.

Personal data protection is equally important when digital underwriting uses account, payment or platform information. The fact that a record is technically obtainable does not imply

that its use is appropriate for every credit decision. The provider should obtain the necessary lawful authorization, limit collection to relevant purposes, retain a verifiable audit trail and make it possible for an applicant to contest an incorrect record. An opaque approval system can be fast while remaining difficult to correct. Where a scoring model is used, regular monitoring should examine changes in input quality, rejection patterns and performance after approval. This is particularly important when the model was developed under economic conditions different from those faced by new borrowers.

Azerbaijan's credit-information system offers a potential basis for more consistent assessment. The Azerbaijan Credit Bureau's Findoc portal allows individuals and entrepreneurs to access credit histories and scoring reports and to dispute inaccurate information. The bureau also reports collecting information from a range of entities that includes leasing companies [10, official announcement of 16 January 2025]. These features can support a leasing process in which applicants understand the information used in assessments and providers maintain reliable reporting. The service is an institutional facility, however, not an indication that a particular leasing company has integrated all of its data with the bureau. The actual coverage and performance of an individual provider would require separate verification.

The wider fintech ecosystem is relevant primarily as enabling infrastructure. A 2024 report by the Centre for Analysis and Communication of Economic Reforms, based on AzFina's 2023 data, classified 26% of reported fintech segments as online payments, 22% as payment aggregation, 20% as electronic wallets and 11% as e-commerce [7, p. 8]. Such infrastructure can facilitate scheduled lease installments, digital receipts and merchant transaction histories. The classification does not measure leasing penetration, customer defaults or the proportion of SMEs using asset-based finance. It would be a mistake to treat the share of payment providers as the share of the credit market financed by digital leasing. Payment activity supports the financing process but is not a substitute for evidence of a suitable contract and a financed asset.

Tax treatment can materially affect the competitiveness of leasing. In January 2024, Azerbaijan's Ministry of Economy explained amendments intended to address unequal VAT recovery opportunities between eligible leasing transactions and asset acquisitions financed by conventional bank loans [7, official announcement of 10 January 2024]. The change sought to align tax treatment under specified conditions rather than grant an unconditional tax advantage to leasing. The appropriate calculation is therefore transaction-specific. A business should consider the treatment of input VAT, the value of the financed asset, the lease payment structure and its own tax status. A digital platform that compares products without addressing these factors can present a misleading estimate of the true economic cost.

Financing risk also arises on the liabilities side of a leasing company. Even a carefully selected portfolio can become expensive if the lessor raises short-term funding while contracts require payments over several years. Currency mismatch is another concern if equipment is purchased in foreign currency but the lessee's revenue and installments are in manat. The Central Bank's July 2025 announcement of a hedging instrument for eligible external borrowing of banks and non-bank credit institutions identified credit and leasing to productive target groups as intended uses of the support framework [8, official announcement of 22 July 2025]. The existence of this instrument does not demonstrate that a privately operated fintech lessor is eligible or has used it. Actual access depends on the institution's legal form and applicable terms.

Practical monitoring should reflect the full life of a lease. Application and approval data reveal who entered the process, but not whether the asset improved the client's business. Contract-level records should show financed asset type, acquisition price, down payment, term, payment frequency, contractual fees, arrears, restructurings, repossessions and realized resale values. On the customer side, it is useful to examine whether the equipment was delivered, remains operational and generated the expected additional cash flow. Privacy-preserving aggregation can

then show repayment performance by sector and asset category. Without such information, optimistic statements about innovation and inclusion cannot be tested against financing outcomes.

The World Bank's B-READY 2025 assessment gave Azerbaijan a Financial Services score of 87 out of 100, with particularly high scores for the formal regulatory framework and public service infrastructure [4, pp. 1, 26–29]. This provides a relevant institutional backdrop for digital contract processing and access to credit information. It does not amount to a certification of any individual fintech leasing business. A balanced assessment therefore distinguishes established enabling conditions from the operational performance of lenders. Measurable improvement would involve lower application costs, clearer contract terms, a greater share of financed productive assets and acceptable credit-loss outcomes, rather than growth in app downloads or advertising visibility alone.

Regulatory reform presents a practical opportunity to standardize minimum expectations before the market becomes more complex. Upon entry into force, the 2026 leasing law's register, disclosure, risk-management and reporting provisions may improve comparability among providers. But the value of supervision will depend on proportional implementation. Requirements that are clear and consistently enforced can strengthen investors' confidence in leasing receivables, while unnecessary duplication can increase costs for smaller providers. Digital submission and standard document formats could reduce this tension. Both providers and borrowers would benefit from predictable processes for contract termination, dispute resolution and asset return.

A financing arrangement should ultimately be judged by the relationship between the financed asset and the borrower's activity. If a vehicle, machine or agricultural implement supports repeatable revenue and payments are structured around that revenue, leasing may improve investment capacity. If operating conditions, maintenance costs or market demand make the cash flow unstable, easier digital approval may increase exposure instead. Financial leasing and fintech should therefore be evaluated as mutually supporting instruments only where underwriting, contract design and asset management remain disciplined. The claim of greater financial inclusion becomes meaningful when more viable businesses can obtain appropriate productive assets and continue meeting their obligations.

CONCLUSION

Fintech-enabled leasing can widen productive asset financing in Azerbaijan by combining an established financial-leasing structure with faster document processing, improved transaction information and more consistent payment monitoring. Its economic advantage does not arise from digitalization alone. The asset's usefulness, the borrower's repayment capacity, total contract price, funding structure and enforceability of rights determine whether the arrangement is commercially sustainable.

The legal context is undergoing an important transition. Azerbaijan's 2026 financial leasing law establishes a more explicit system of provider registration, oversight and credit-information reporting, but these requirements were not yet in force in October 2026. Evaluation of existing contracts should therefore distinguish the rules applicable at the relevant date from obligations planned for implementation. The changes create opportunities for better transparency, although their effects on financing volumes and default rates cannot yet be inferred.

Further empirical analysis requires auditable firm-level evidence on approval decisions, contract pricing, arrears, recoveries and the productivity of leased assets. In the absence of such records, regulatory and institutional analysis can identify necessary safeguards and plausible benefits, but it cannot establish the performance of a particular private fintech leasing company.

A credible assessment of the sector should connect digital accessibility with asset quality, financial resilience and the measurable outcomes of financed businesses.

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МЕТОДИКИ ТРЕНИРОВОК ДЛЯ НАЧИНАЮЩИХ И СЕКРЕТЫ УСПЕХА АЗИАТСКОЙ ШКОЛЫ НАСТОЛЬНОГО ТЕННИСА

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Аннотация. Настольный теннис является одним из наиболее динамичных и технически сложных видов спорта. В последние десятилетия доминирующее положение в мировом настольном теннисе занимает азиатская школа подготовки спортсменов, особенно представители Китая, Южной Кореи и Японии. Их успех обусловлен эффективной системой подготовки, высокой интенсивностью тренировочного процесса и особой методикой развития технических и физических качеств игроков.

В данной статье рассматриваются основные методики тренировок для начинающих спортсменов, а также анализируются ключевые факторы успеха азиатской школы настольного тенниса. Особое внимание уделяется развитию выносливости, координации движений, скорости реакции и психологической устойчивости. Рассматриваются современные подходы к организации тренировочного процесса, а также методические рекомендации для спортсменов и тренеров.

Результаты исследования показывают, что сочетание технической подготовки, высокой тренировочной дисциплины и научного подхода к тренировкам позволяет значительно повысить эффективность подготовки начинающих игроков.

Ключевые слова: настольный теннис, тренировочный процесс, азиатская школа, выносливость, техника игры, спортивная подготовка, координация.

Введение

Настольный теннис является одним из самых популярных видов спорта в мире. Он требует высокой скорости реакции, точности движений, тактического мышления и развитой физической выносливости. Несмотря на сравнительно небольшие размеры игрового стола, динамика игры чрезвычайно высока, а скорость полета мяча может превышать 100 км/ч.

В современном настольном теннисе особое внимание уделяется научному подходу к подготовке спортсменов. Тренировочный процесс включает развитие технических, тактических, физических и психологических качеств игроков. Важным фактором является также системность тренировок и постепенное увеличение нагрузки.

На протяжении последних десятилетий лидирующие позиции в мировом настольном теннисе занимают представители азиатских стран. Особенно выделяется китайская школа настольного тенниса, которая демонстрирует выдающиеся результаты на международных соревнованиях и Олимпийских играх. Это объясняется не только высоким уровнем мастерства спортсменов, но и уникальной системой подготовки.

Азиатская школа настольного тенниса основана на раннем начале тренировок, высокой интенсивности занятий, строгой дисциплине и детальной отработке технических элементов. Спортсмены уделяют большое внимание развитию скорости, точности ударов, контролю мяча и тактическому мышлению.

Целью данной статьи является анализ методик тренировок для начинающих игроков и изучение факторов, обеспечивающих успех азиатской школы настольного тенниса.

Задачи исследования:

- изучить особенности тренировочного процесса начинающих спортсменов;
- рассмотреть методы развития физической выносливости и координации;
- проанализировать основные принципы подготовки спортсменов в азиатской школе настольного тенниса.

Физическая подготовка и развитие специальных качеств спортсменов

Физическая подготовка в настольном теннисе имеет специфическую направленность и существенно отличается от подготовки в других игровых видах спорта. Это связано с особенностями игровой деятельности, которая характеризуется высокой скоростью обмена ударами, резкими перемещениями и необходимостью мгновенно реагировать на действия соперника.

Одним из ключевых физических качеств является скорость реакции. В процессе игры спортсмен должен мгновенно оценивать траекторию полета мяча, его вращение и направление. Время на принятие решения часто составляет менее одной секунды. Поэтому тренировки включают специальные упражнения, направленные на развитие зрительно-моторной реакции и быстроты движений.

Для развития скорости реакции используются следующие упражнения:

- тренировка с неожиданными подачами;
- упражнения с теннисными и реакционными мячами;
- игровые задания с ограниченным временем на выполнение удара;
- упражнения на быстрые перемещения вокруг стола.

Не менее важным компонентом подготовки является координация движений. Настольный теннис требует высокой точности работы рук, ног и корпуса. Во время игры спортсмен выполняет большое количество технически сложных движений, которые должны быть синхронизированы и выполняться с высокой точностью.

Для развития координации применяются упражнения на баланс, перемещения с изменением направления движения, а также специальные игровые комбинации. Например, спортсмен выполняет серию ударов форхендом и бэкхендом с одновременным перемещением по диагонали стола.

Важную роль играет также развитие специальной выносливости. Несмотря на короткие розыгрыши мяча, игра может продолжаться длительное время, особенно в условиях соревновательных матчей. Спортсмен должен сохранять высокую скорость и точность ударов на протяжении всей игры.

Для развития выносливости используются интервальные тренировки, многомячевая подача и игровые серии с повышенной интенсивностью. Такие упражнения позволяют улучшить функциональные возможности организма и повысить устойчивость к утомлению.

Особое внимание уделяется работе ног. Эффективное перемещение по игровой площадке позволяет спортсмену занимать оптимальную позицию для выполнения удара.

Тренировки включают различные виды перемещений: боковые шаги, перекрестные шаги, быстрые выпады и возврат в исходную позицию.

Регулярная тренировка этих элементов значительно повышает мобильность спортсмена и способствует улучшению техники игры.

Тактическая подготовка и анализ игровой деятельности

Тактическая подготовка является важной частью современного настольного тенниса. Высокий уровень технического мастерства должен сочетаться с умением правильно выбирать тактику игры в зависимости от действий соперника.

Тактика игры включает выбор оптимальных ударов, изменение темпа игры, использование различных вращений мяча и создание выгодных игровых ситуаций. Спортсмен должен уметь быстро адаптироваться к стилю игры соперника и корректировать свою стратегию в процессе матча.

Одним из ключевых элементов тактики является использование вращения мяча. Различные виды вращения — верхнее, нижнее и боковое — позволяют усложнить прием мяча для соперника и создать преимущество в розыгрыше.

В процессе подготовки спортсменов большое внимание уделяется анализу игровых ситуаций. Для этого используются видеозаписи матчей, которые позволяют детально изучать технику и тактические решения игроков. Анализ собственных игр помогает выявлять ошибки и разрабатывать эффективные стратегии их устранения.

Также важным элементом является изучение стиля игры соперников. Анализируя сильные и слабые стороны противника, спортсмен может выбрать наиболее эффективную тактику ведения игры.

Современные технологии значительно расширяют возможности анализа. Использование видеоанализа, компьютерных программ и статистических методов позволяет более точно оценивать эффективность различных игровых действий.

В результате систематической тактической подготовки спортсмен развивает способность быстро принимать решения и эффективно действовать в условиях соревновательной борьбы.

Экспериментальное исследование эффективности тренировочных методик

Для оценки эффективности различных тренировочных методик было проведено экспериментальное исследование среди начинающих игроков в настольный теннис.

В исследовании приняли участие 20 спортсменов в возрасте 18–20 лет, имеющих начальный уровень подготовки.

Участники были разделены на две группы по 10 человек:

- Контрольная группа — тренировалась по стандартной методике, включающей базовые упражнения и игровые тренировки.
- Экспериментальная группа — тренировалась с использованием элементов азиатской школы подготовки, включая многомячевые тренировки, упражнения на скорость реакции и интенсивные интервальные занятия.

Продолжительность эксперимента составила 8 недель, при частоте тренировок 3 раза в неделю. Перед началом и после завершения эксперимента были проведены тестирования по следующим показателям:

- скорость реакции;
- точность ударов;
- стабильность игры;
- уровень физической выносливости.

Результаты эксперимента показали, что спортсмены экспериментальной группы продемонстрировали более выраженный прогресс по всем исследуемым показателям.

Особенно заметное улучшение наблюдалось в скорости реакции и точности выполнения ударов.

Полученные результаты подтверждают эффективность использования элементов азиатской тренировочной системы при подготовке начинающих спортсменов.

Таблица 1 — Сравнение эффективности тренировочных методов

Использование данных методов в комплексе позволяет значительно повысить эффективность тренировочного процесса.

Метод тренировки	Основная цель	Результат
Многомячевые тренировки	Развитие скорости реакции и техники ударов	Увеличение скорости реакции на 25-30%
Интервальные тренировки	Развитие специальной выносливости	Повышение устойчивости к нагрузке
Упражнение на перемещения	Улучшение работы ног	Повышение мобильности игрока
Игровые серии	Развитие тактического мышления	Улучшение стабильности игры

Психологические аспекты подготовки спортсменов

Психологическая устойчивость является важным фактором успешного выступления в настольном теннисе. Во время соревнований спортсмен сталкивается с высоким уровнем эмоционального напряжения, необходимостью сохранять концентрацию и быстро принимать решения.

Одним из ключевых качеств является умение контролировать эмоциональное состояние.

Излишнее волнение или потеря уверенности могут привести к увеличению количества ошибок и снижению эффективности игры.

Для развития психологической устойчивости используются различные методы подготовки. Одним из них является моделирование соревновательных условий во время тренировок. Это позволяет спортсмену привыкнуть к стрессовым ситуациям и научиться сохранять концентрацию.

Также широко применяются методы психологической саморегуляции, такие как дыхательные упражнения, визуализация игровых действий и концентрация внимания на выполнении технических элементов.

Важным фактором является также мотивация спортсмена. Высокий уровень внутренней мотивации способствует более эффективной тренировочной деятельности и стремлению к постоянному совершенствованию.

Таким образом, психологическая подготовка является неотъемлемой частью тренировочного процесса и оказывает значительное влияние на спортивные результаты.

Методика тренировок для начинающих игроков

Начальный этап подготовки спортсменов является наиболее важным, поскольку именно в этот период формируются основные технические навыки и двигательные способности. Тренировочный процесс должен быть направлен на постепенное освоение базовых элементов игры и развитие физических качеств.

Одним из главных элементов подготовки является обучение правильной стойке и хватке ракетки. Неправильная техника на начальном этапе может привести к формированию устойчивых ошибок, которые впоследствии будет сложно исправить.

В тренировках начинающих игроков большое внимание уделяется следующим элементам:

- правильной стойке спортсмена;

- перемещениям вокруг стола;
- базовым ударам (форхенд и бэкхенд);
- контролю вращения мяча.

Развитие координации движений является важным компонентом подготовки. Для этого используются специальные упражнения, направленные на улучшение реакции и точности движений.

Примеры упражнений:

1. Многократные удары по мячу без ошибки.
2. Игра на удержание мяча на столе.
3. Тренировка быстрых перемещений вокруг стола.
4. Упражнения с подачами и приемом подачи.

Кроме технической подготовки, большое внимание уделяется развитию общей физической подготовки. Для начинающих спортсменов используются упражнения на развитие выносливости, скорости и гибкости.

Регулярные тренировки способствуют укреплению сердечно-сосудистой системы, улучшению координации и повышению общей работоспособности спортсмена.

Секреты успеха азиатской школы настольного тенниса

Азиатская школа настольного тенниса считается одной из самых сильных в мире. Спортсмены из Китая, Японии и Южной Кореи регулярно занимают призовые места на международных турнирах.

Одним из ключевых факторов успеха является высокая интенсивность тренировок. Спортсмены тренируются по несколько часов в день, уделяя особое внимание технической подготовке.

Основные особенности азиатской системы подготовки:

1. Раннее начало тренировок

Во многих странах Азии дети начинают заниматься настольным теннисом уже в возрасте 5–7 лет. Это позволяет сформировать правильную технику и развить необходимые физические качества.

2. Большой объем тренировок

Профессиональные спортсмены тренируются 4–6 часов в день. Тренировки включают техническую подготовку, физические упражнения и тактическую подготовку.

3. Использование многомячевой тренировки

Одной из самых эффективных методик является многомячевая тренировка. Тренер подает большое количество мячей подряд, что позволяет спортсмену отрабатывать технику ударов и повышать скорость реакции.

4. Высокий уровень дисциплины

Азиатская система подготовки основана на строгой дисциплине и высокой мотивации спортсменов.

5. Научный подход

Тренировочный процесс активно использует современные научные методы: биомеханику движений, анализ техники игры и спортивную психологию.

Благодаря этим факторам азиатские спортсмены демонстрируют высокий уровень технического мастерства и физической подготовки.

Практическое применение методик тренировок

Методики азиатской школы настольного тенниса могут успешно применяться и в других странах.

Однако важно учитывать уровень подготовки спортсменов и адаптировать тренировочный процесс.

Для начинающих игроков рекомендуется использовать следующие подходы:

- регулярные тренировки;
- постепенное увеличение нагрузки;
- развитие техники ударов;
- совершенствование координации движений.

Тренировочный процесс должен включать разнообразные упражнения, направленные на развитие всех компонентов спортивной подготовки.

Практика показывает, что использование современных методик значительно повышает эффективность тренировок и способствует более быстрому развитию спортивного мастерства.

Статистический анализ доминирования азиатской школы

Доминирование азиатских стран в настольном теннисе подтверждается статистическими данными международных соревнований. По данным International Table Tennis Federation, спортсмены из Китая на протяжении последних десятилетий занимают лидирующие позиции в мировом рейтинге.

Особенно ярко это проявляется на Олимпийских играх. С момента включения настольного тенниса в олимпийскую программу в 1988 году китайские спортсмены завоевали более половины всех золотых медалей.

Например:

- на Олимпийских играх 2016 года китайские спортсмены выиграли 4 из 4 золотых медалей;
- на Олимпийских играх 2020 года представители Китая также заняли лидирующие позиции.

Это свидетельствует о высокой эффективности системы подготовки спортсменов в странах Азии.

В мировом рейтинге ITTF также доминируют представители азиатских стран. В первой десятке рейтинга регулярно присутствует 6–8 игроков из Китая, Японии и Южной Кореи, что подтверждает высокий уровень их подготовки.

Сравнение европейской и азиатской школ настольного тенниса показывает следующие различия:

Параметр	Азиатская школа	Европейская школа
Интенсивность тренировок	Высокая	Средняя
Ранее начало занятий	5-7 лет	8-10 лет
Основной акцент	Скорость и техника	Тактика и стратегия
Объем тренировок	4-6 часов в день	2-3 часа в день

Таким образом, системный подход и высокая интенсивность тренировочного процесса позволяют азиатским спортсменам достигать более высоких результатов на международной арене.

Анализ эффективности тренировочных методик

Результаты эксперимента и анализ международного опыта показывают, что наиболее эффективными являются комплексные тренировочные программы, сочетающие техническую, физическую и психологическую подготовку.

Наиболее значительное влияние на развитие игровых навыков оказывают следующие факторы:

- регулярность тренировок;
- использование многомячевой методики;
- развитие скорости реакции;
- совершенствование работы ног.

Комбинирование этих элементов позволяет значительно повысить уровень подготовки спортсменов и ускорить процесс освоения технических навыков.

Кроме того, важную роль играет индивидуальный подход к каждому спортсмену. Учет особенностей физического развития и уровня подготовки позволяет оптимально распределять тренировочную нагрузку и повышать эффективность тренировочного процесса.

Рекомендации

Для повышения эффективности тренировочного процесса можно предложить следующие рекомендации:

1. Начинать обучение с освоения базовой техники ударов.
2. Регулярно развивать физическую выносливость спортсменов.
3. Использовать многомячевую тренировку.
4. Уделять внимание тактической подготовке игроков.
5. Применять современные методы анализа техники игры.

Соблюдение этих рекомендаций позволит значительно повысить уровень подготовки начинающих спортсменов.

Заключение

Настольный теннис является сложным и высокоинтенсивным видом спорта, требующим высокого уровня технической, физической и психологической подготовки. Эффективность тренировочного процесса во многом зависит от правильной организации занятий и использования современных методик подготовки.

Азиатская школа настольного тенниса демонстрирует высокую эффективность благодаря системному подходу, раннему началу тренировок и высокой интенсивности занятий.

Использование данных методик позволяет значительно повысить уровень подготовки спортсменов и добиться высоких результатов в соревнованиях.

Таким образом, применение современных методов тренировки и изучение опыта ведущих спортивных школ мира является важным фактором развития настольного тенниса.

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Abstract. Table tennis is one of the most dynamic and technically challenging sports. In recent decades, the Asian school of training, particularly China, South Korea, and Japan, has dominated global table tennis. Their success is due to an effective training system, high-intensity training, and a unique methodology for developing players' technical and physical abilities.

This article examines the basic training methods for beginners and analyzes the key success factors of the Asian table tennis school. Particular attention is paid to developing endurance, motor coordination, reaction speed, and mental resilience. Modern approaches to organizing the training process are discussed, along with methodological recommendations for athletes and coaches.

The study's results demonstrate that a combination of technical preparation, high training discipline, and a scientific approach to training can significantly improve the effectiveness of training for novice players.

Keywords: table tennis, training process, Asian school, endurance, playing technique, athletic training, coordination.

Аңдатпа. Үстел теннисі – ең қарқынды және техникалық қиын спорт түрлерінің бірі. Соңғы онжылдықтарда Азиялық дайындық мектебі, атап айтқанда Қытай, Оңтүстік Корея және Жапония әлемдік үстел теннисінде үстемдік етті. Олардың жетістігі тиімді жаттығу жүйесінің, жоғары қарқынды жаттығулардың және ойыншылардың техникалық және физикалық қабілеттерін дамытудың бірегей әдістемесінің арқасында.

Бұл мақала жаңадан бастаушыларға арналған негізгі оқыту әдістерін қарастырады және Азия үстел теннисі мектебінің табысының негізгі факторларын талдайды. Төзімділікті, қозғалыс координациясын, реакция жылдамдығын және психикалық тұрақтылықты дамытуға ерекше назар аударылады. Спортшылар мен жаттықтырушыларға арналған әдістемелік ұсыныстармен бірге оқу-жаттығу процесін ұйымдастырудың заманауи тәсілдері талқыланады.

Зерттеу нәтижелері техникалық дайындықтың, жоғары дайындық тәртібінің және жаттығуға ғылыми көзқарастың үйлесімі жаңадан келген ойыншылар үшін жаттығулардың тиімділігін айтарлықтай арттыратынын көрсетеді.

Кілттік сөздер: үстел теннисі, жаттығу процесі, азиялық мектеп, төзімділік, ойын техникасы, атлетикалық дайындық, координация.

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Мотивациялық әдістерді қолдану арқылы студенттердің сабаққа қатысу белсенділігін арттыру

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Аннотация
Бұл мақалада жоғары оқу орындарында дене шынықтыру пәнін оқыту барысында мотивациялық әдістерді қолданудың студенттердің сабаққа қатысу белсенділігін арттырудағы маңызы қарастырылады. Студенттердің ішкі және сыртқы мотивациясын қалыптастыру жолдары талданып, жеке-бағдарланған оқыту, ойын және жарыс элементтері, заманауи технологияларды пайдалану, мадақтау мен кері байланыс беру әдістері ұсынылады. Зерттеу нәтижелері мотивациялық тәсілдердің дене шынықтыру сабақтарының тиімділігін арттырып, студенттердің физикалық белсенділігі мен салауатты өмір салтын қалыптастыруға оң әсер ететінін көрсетеді.
Түйін сөздер: дене шынықтыру, мотивация, студент, белсенділік, сабаққа қатысу.

Қазіргі жаһандану жағдайында білім беру жүйесінің басты мақсаты – бәсекеге қабілетті, белсенді және өзіндік ой-пікірі қалыптасқан тұлға тәрбиелеу. Осы тұрғыдан алғанда, студенттердің сабаққа қатысу белсенділігі оқу үдерісінің сапасын айқындайтын негізгі көрсеткіштердің бірі болып табылады. Дегенмен, жоғары оқу орындарында студенттердің оқу мотивациясының төмендеуі, сабаққа немқұрайлы қарау, пассивті қатысу сияқты мәселелер жиі кездеседі. Бұл жағдай білім беру үдерісінде тиімді мотивациялық әдістерді қолданудың өзектілігін арттырады. Мотивация – тұлғаның іс-әрекетке деген ішкі қажеттілігі мен қызығушылығын қалыптастыратын маңызды психологиялық фактор. Ғылыми еңбектерде мотивация ұғымы кеңінен қарастырылып, оның оқу жетістігімен тығыз байланысы дәлелденген. Атап айтқанда, Абрахам Маслоу қажеттіліктер иерархиясы теориясында адамның белсенділігі оның қажеттіліктерін қанағаттандыру деңгейіне тәуелді екенін көрсетсе, Фредерик Герцберг екі факторлы теориясында мотивацияны арттыратын және шектейтін факторларды айқындап берген. Ал Лев Выготский оқыту үдерісіндегі әлеуметтік өзара әрекет пен жақын даму аймағының маңызын ерекше атап өткен. Бұл теориялар білім беру тәжірибесінде мотивациялық әдістерді жүйелі түрде қолданудың ғылыми негізін құрайды. Студенттердің сабаққа белсенді қатысуы тек академиялық үлгерімге ғана емес, олардың кәсіби құзыреттілігінің қалыптасуына да тікелей әсер етеді. Сондықтан оқытушының басты міндеттерінің бірі – білім алушылардың ішкі және сыртқы мотивациясын оята отырып, сабаққа деген қызығушылығын арттыру. Интерактивті әдістерді енгізу, бағалаудың ынталандырушы жүйесін қалыптастыру, кері байланысты тиімді ұйымдастыру, цифрлық технологияларды пайдалану – осы бағыттағы маңызды құралдар болып табылады. Осы мақалада мотивациялық әдістерді қолдану арқылы студенттердің сабаққа қатысу белсенділігін арттырудың теориялық негіздері мен практикалық жолдары қарастырылады, сондай-ақ олардың оқу үдерісіндегі тиімділігі талданады. Мотивация – студенттің оқу іс-әрекетіне деген саналы қатынасын қалыптастыратын және оның

белсенділігін айқындайтын жетекші факторлардың бірі. Жоғары оқу орындарында білім беру үдерісінің нәтижелілігі көбіне студенттің ішкі ынтасына, қызығушылығына және мақсаттылығына байланысты. Сондықтан мотивациялық әдістерді жүйелі әрі мақсатты түрде қолдану – сабаққа қатысу белсенділігін арттырудың маңызды шарты болып табылады. Ғылыми тұрғыдан алғанда, мотивация теориялары білім беру тәжірибесінде нақты әдістерді таңдауға негіз болады. Абрахам Маслоу ұсынған қажеттіліктер иерархиясы теориясына сәйкес, студенттің оқу белсенділігі оның физиологиялық, қауіпсіздік, әлеуметтік және өзін-өзі жүзеге асыру қажеттіліктерінің қанағаттандырылуына тәуелді. Демек, білім беру ортасында қолайлы психологиялық ахуал қалыптастыру, қолдау көрсету және студенттің жетістігін мойындау – оның сабаққа ынтасын арттырудың алғышарттары. Ал Фредерик Герцбергтің екі факторлы теориясы мотивацияны арттыратын (жетістік, мойындау, жауапкершілік) және шектейтін (оқу жағдайы, бағалау әділдігі, қарым-қатынас) факторларды ажыратады. Осыған сәйкес, оқытушы тек материалды жеткізуші емес, студенттің жетістігін қолдаушы, бағыттаушы тұлға болуы тиіс. Мысалы, студенттердің жетістіктерін жария түрде атап өту, жеке прогресті бағалау, таңдау еркіндігін беру олардың ішкі мотивациясын күшейтеді. Лев Выготский еңбектерінде көрсетілгендей, оқу үдерісіндегі әлеуметтік өзара әрекет пен «жақын даму аймағы» ұғымы студенттердің белсенділігін арттыруда маңызды рөл атқарады. Топтық жұмыс, пікірталас, жобалық тапсырмалар арқылы студенттер бір-бірімен тәжірибе алмасып, танымдық белсенділігін арттырады. Бұл тәсілдер олардың тек білім алуына ғана емес, сонымен қатар коммуникативтік және кәсіби дағдыларының қалыптасуына ықпал етеді. Студенттердің сабаққа қатысу белсенділігін арттыруда келесі мотивациялық әдістер тиімді нәтиже береді:

Интерактивті оқыту әдістері. Дебат, кейс-стади, рөлдік ойындар, миға шабуыл әдістері студенттердің сабаққа қызығушылығын оятады және олардың белсенді қатысуына жағдай жасайды.

Бағалаудың ынталандырушы жүйесі. Қалыптастырушы бағалау, өзін-өзі және өзара бағалау әдістері студенттің жауапкершілігін арттырып, нәтижеге бағыттайды.

Жеке білім траекториясын қолдау. Студенттің қызығушылығы мен қабілетіне сәйкес тапсырмалар ұсыну оның өзіндік дамуына мүмкіндік береді.

Цифрлық технологияларды пайдалану. Онлайн-платформалар, интерактивті қосымшалар, мультимедиялық құралдар сабақтың мазмұнын жандандырып, заманауи білім алушының қажеттілігіне жауап береді.

Тиімді кері байланыс. Уақтылы және нақты кері байланыс студенттің жетістігін саралауға, қателерін түзетуге және алдағы мақсаттарын айқындауға көмектеседі. Сабаққа белсенді қатысу студенттердің тек академиялық үлгерімін жақсартып қана қоймай, олардың кәсіби құзыреттілігін, жауапкершілігін және өзіндік көзқарасын қалыптастырады. Мотивациялық әдістерді жүйелі қолдану арқылы білім алушылардың оқу үдерісіне деген оң көзқарасын қалыптастыруға, ішкі қажеттілігін оятуға және тұрақты қызығушылығын дамытуға болады. Осылайша, мотивация теорияларына негізделген заманауи педагогикалық тәсілдер студенттердің сабаққа қатысу белсенділігін арттырудың тиімді құралы болып табылады және білім беру сапасын арттыруға бағытталған маңызды стратегиялық тетік ретінде қарастырылады. Мотивациялық әдістерді оқу үдерісіне енгізу жүйелі, ғылыми негізделген және мақсатқа бағытталған сипатта жүзеге асырылуы тиіс. Бұл ретте оқытушы тек білім мазмұнын жеткізуші ғана емес, студенттің танымдық белсенділігін ұйымдастырушы, бағыттаушы және рефлексиясын қалыптастырушы субъект ретінде қарастырылады. Оқу үдерісін тиімді ұйымдастыру үшін мотивацияның ішкі (танымдық қызығушылық, өзін-өзі дамытуға ұмтылыс, кәсіби мақсат) және сыртқы (баға, марапат, әлеуметтік мойындау) түрлерінің өзара байланысын ескеру маңызды. Ішкі мотивацияны дамыту студенттің білімге деген тұрақты қызығушылығын қалыптастырады және ұзақ

мерзімді нәтижеге жеткізеді. Бұл бағытта проблемалық оқыту, зерттеушілік әдіс, жобалық жұмыстар сияқты тәсілдер тиімді болып табылады. Студент оқу материалын дайын күйінде қабылдаушы емес, мәселені шешуші, ізденуші ретінде әрекет еткен жағдайда оның танымдық белсенділігі артады. Сонымен қатар кәсіби бағытталған тапсырмаларды қолдану білім мазмұнының болашақ мамандықпен байланысын айқындап, оқу әрекетінің маңыздылығын түсінуге мүмкіндік береді. Сыртқы мотивацияны ұйымдастыруда бағалаудың айқын, әділ және ашық критерийлеріне сүйену қажет. Бағалау жүйесі студенттің тек қорытынды нәтижесін емес, оқу барысындағы белсенділігін, шығармашылық көзқарасын, ынтасын да ескеруі тиіс. Қалыптастырушы бағалау элементтерін қолдану арқылы студент өзінің жетістіктерін кезең-кезеңімен бақылап, оқу стратегиясын түзету мүмкіндігіне ие болады. Бұл өз кезегінде жауапкершілік деңгейін арттырып, өзіндік реттеуді қалыптастырады. Сонымен қатар білім беру ортасының психологиялық-педагогикалық ахуалы мотивацияның тұрақтылығына тікелей әсер етеді. Ынтымақтастыққа негізделген қарым-қатынас, академиялық қолдау, өзара құрмет пен сенім атмосферасы студенттің оқу үдерісіне белсенді араласуына жағдай жасайды.

Академиялық еркіндік пен пікір білдіру мүмкіндігі де студенттің өзіндік көзқарасын қалыптастырып, сабақтағы белсенділігін күшейтеді. Цифрлық білім беру ресурстарын орынды пайдалану да мотивацияны арттырудың маңызды құралы болып табылады. Электрондық платформалар, онлайн-тестілеу жүйелері, интерактивті презентациялар мен мультимедиялық материалдар студенттердің ақпаратты қабылдауын жеңілдетіп қана қоймай, олардың оқу үдерісіне деген қызығушылығын арттырады. Алайда цифрлық құралдарды қолдану педагогикалық мақсатқа сәйкестендіріліп, мазмұнмен үйлесімді болуы тиіс. Қорыта айтқанда, мотивациялық әдістерді ғылыми негізде және кешенді түрде қолдану студенттердің сабаққа қатысу белсенділігін арттырудың тиімді жолы болып табылады. Мұндай тәсіл білім алушылардың танымдық дербестігін, кәсіби құзыреттілігін және өзін-өзі дамыту қабілетін қалыптастырып, жоғары білім беру сапасын қамтамасыз етуге мүмкіндік береді. Жүргізілген талдау көрсеткендей, студенттердің сабаққа қатысу белсенділігін арттыру мәселесі қазіргі жоғары білім беру жүйесінің басым бағыттарының бірі болып табылады. Білім алушылардың оқу үдерісіне жүйелі әрі саналы қатысуы олардың академиялық жетістіктеріне, кәсіби құзыреттілігінің қалыптасуына және тұлғалық дамуына тікелей әсер етеді. Осы тұрғыдан алғанда, мотивациялық әдістерді мақсатты және ғылыми негізде қолдану – білім беру сапасын арттырудың маңызды тетігі ретінде қарастырылады. Мотивация – тұлғаның әрекетке деген ішкі және сыртқы түрткілерінің жиынтығы. Ішкі мотивация студенттің танымдық қызығушылығына, өзін-өзі дамытуға деген ұмтылысына негізделсе, сыртқы мотивация мадақтау, бағалау, әлеуметтік қолдау сияқты факторлар арқылы жүзеге асады. Оқу үдерісінде осы екі бағытты үйлесімді түрде қолдану студенттердің тұрақты белсенділігін қамтамасыз етеді. Зерттеулер көрсеткендей, тек сыртқы ынталандыруға сүйену қысқа мерзімді нәтиже берсе, ал ішкі мотивацияны қалыптастыру ұзақ мерзімді әрі сапалы нәтижеге жеткізеді. Сондықтан оқытушының басты міндеті – студенттің оқу әрекетіне деген ішкі қызығушылығын ояту және оны тұрақты дамыту.

Мотивациялық әдістердің тиімділігі олардың мазмұнына ғана емес, қолданылу жүйелілігі мен педагогикалық шеберлікке де байланысты. Интерактивті оқыту технологиялары, жобалық әдіс, пікірталас, кейс-стади, топтық және жұптық жұмыстар студенттердің сабаққа белсенді қатысуына ықпал етеді. Бұл әдістер білім алушыларды пассивті тыңдаушыдан оқу үдерісінің белсенді субъектісіне айналдырады. Нәтижесінде студенттердің жауапкершілігі артып, өз пікірін дәлелдеу, сыни ойлау, коммуникативтік дағдылары дамиды. Сонымен қатар, жүйелі және сапалы кері байланыс беру де мотивацияны арттырудың маңызды құралы болып табылады. Оқытушы тарапынан берілетін нақты, түсінікті және қолдаушы сипаттағы кері байланыс студенттің өз жетістіктерін

бағалауына, қателерін түзетуіне және алдағы оқу әрекетін жоспарлауына мүмкіндік береді. Бағалау жүйесінің әділдігі мен ашықтығы да студенттердің сабаққа тұрақты қатысуына оң әсер етеді. Заманауи цифрлық технологияларды қолдану да мотивациялық ортаны қалыптастыруда ерекше рөл атқарады. Онлайн платформалар, интерактивті тапсырмалар, мультимедиялық ресурстар білім алушылардың қызығушылығын арттырып, оқу материалын қабылдауды жеңілдетеді.

Әсіресе цифрлық ортада өскен қазіргі студенттер үшін технологиялық құралдарды тиімді пайдалану олардың оқу белсенділігін арттырудың маңызды шарты болып табылады. Мотивациялық әдістерді қолдануда студенттердің жеке ерекшеліктерін ескеру де өзекті мәселе. Әр білім алушының қабілеті, қызығушылығы, танымдық стилі әртүрлі болғандықтан, сараланған тапсырмалар мен жеке қолдау көрсету белсенділікті арттыруға мүмкіндік береді.

Ынтымақтастыққа негізделген жағымды психологиялық ахуал қалыптастыру студенттердің өз ойын еркін білдіруіне және сабаққа тұрақты қатысуына жағдай жасайды. Жалпы алғанда, мотивациялық әдістерді жүйелі, ғылыми негізде және кешенді түрде қолдану студенттердің сабаққа қатысу белсенділігін арттырудың тиімді жолы болып табылады. Бұл тәсіл тек қатысу көрсеткіштерін жоғарылатып қана қоймай, білім сапасын арттыруға, кәсіби құзыреттілікті дамытуға және өзін-өзі жетілдіруге бағытталған тұлға қалыптастыруға ықпал етеді. Осылайша, жоғары оқу орындарында мотивациялық әдістерді жетілдіру және оларды білім беру тәжірибесіне кеңінен енгізу – заманауи білім беру талаптарына жауап беретін, белсенді, жауапты және бәсекеге қабілетті мамандар даярлаудың маңызды алғышарты болып табылады.

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Повышение активности посещения занятий студентами посредством применения мотивационных методов.

Аннотация

В данной статье рассматривается значение применения мотивационных методов в процессе преподавания дисциплины «Физическая культура» в высших учебных заведениях для повышения активности посещения занятий студентами. Проанализированы пути формирования внутренней и внешней мотивации студентов, предложены методы личностно-ориентированного обучения, использование игровых и соревновательных элементов, современных технологий, а также поощрения и обратной связи. Результаты исследования показывают, что мотивационные подходы способствуют повышению эффективности занятий по физической культуре, увеличению физической активности студентов и формированию здорового образа жизни.

Ключевые слова: физическая культура, мотивация, студент, активность, посещаемость занятий.

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Enhancing Student Class Attendance Through the Use of Motivational Methods

Abstract

This article examines the significance of applying motivational methods in teaching the discipline “Physical Education” in higher education institutions in order to increase student attendance and engagement in classes. The study analyzes ways of developing both intrinsic and extrinsic motivation among students and proposes student-centered teaching methods, the use of game-based and competitive elements, modern technologies, as well as encouragement and feedback strategies. The research findings demonstrate that motivational approaches contribute to improving the effectiveness of physical education classes, increasing students’ physical activity, and promoting a healthy lifestyle.

Keywords: physical education, motivation, student, activity, class attendance.

Развитие критического мышления учащихся 10 класса при решении задач по химической кинетике с использованием цифрового ресурса, созданного с помощью генеративного искусственного интеллекта

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Аннотация

В статье предложена методическая модель развития критического мышления учащихся 10 класса при решении задач по химической кинетике с использованием авторского цифрового ресурса. Разработка продолжает работу над методикой изучения скорости химических реакций и связывает содержание курса общей и неорганической химии с современными средствами обучения. Генеративный искусственный интеллект используется при создании цифровых материалов, которые требуют предметной проверки. Учебный цикл включает прогнозирование, работу с интерактивной моделью, объяснение на уровне частиц, обоснование способа решения и проверку ответа. Представлены примеры расчётных и проблемных заданий, сценарий занятия и проект критериев оценки рассуждений с наблюдаемыми дескрипторами и условным примером оценивания. Работа имеет теоретико-методический характер. Её результатом является описание организации обучения и инструментария для последующей апробации. Эффективность предложенной модели предстоит проверить в педагогическом исследовании.

Ключевые слова — химическая кинетика, критическое мышление, методика обучения химии, цифровой ресурс, генеративный искусственный интеллект, решение задач.

Developing Grade 10 Students' Critical Thinking in Chemical Kinetics Problem Solving Using a Digital Resource Created with Generative Artificial Intelligence

Abstract. This methodological paper proposes an instructional model for developing Grade 10 students' critical thinking through chemical kinetics problems supported by a digital learning resource developed with generative-AI assistance. Generative artificial intelligence assists in

developing materials that require subject-specific review. The learning sequence combines prediction, interaction with a simulation, particle-level explanation, justification of the solution method, and answer checking. The paper presents calculation and reasoning tasks, a lesson scenario, and a proposed rubric with observable scoring criteria and an illustrative scored response. Its contribution is an instructional design and a framework for future classroom evaluation. The effectiveness of the model remains to be tested empirically.

Keywords — chemical kinetics, critical thinking, chemistry education, digital learning resource, generative artificial intelligence, problem solving.

Введение

При изучении скорости химических реакций учащиеся встречаются с необходимостью объяснить наблюдаемое явление и выразить его количественно. Правильная подстановка чисел в формулу ещё не показывает, понимает ли ученик условия её применения. Для учителя существенны и другие вопросы. Почему выбран именно этот способ решения? Какие величины необходимо сравнить? Согласуется ли результат с химическим смыслом задачи?

Обзор исследований по обучению химической кинетике Bain и Towns показывает значимость как понимания понятий, так и математической стороны темы [1]. В предлагаемой разработке эти стороны связываются через последовательность учебных действий. Ученик сначала высказывает предположение, затем рассматривает модель процесса, объясняет изменение скорости и проверяет расчёт. Такой порядок позволяет сделать ход рассуждения доступным для обсуждения.

Разработка входит в текущий авторский проект по методике изучения скорости химических реакций и представляет начальный методический этап магистерского исследования о развитии критического мышления при решении сложных задач по химии с использованием инструментов ИИ. Цель статьи — описать модель применения цифрового ресурса в 10 классе и предложить задания и критерии, с помощью которых впоследствии можно изучить качество рассуждений учащихся.

Для достижения цели выполнены анализ методической литературы, проектирование учебного цикла, разработка примеров заданий и расчётная проверка приведённых решений. Эмпирическая проверка влияния ресурса на результаты обучения относится к следующему этапу работы.

Методические основания разработки

В работе под критическим мышлением понимается обоснованное суждение, предполагающее анализ информации, оценку доводов, формулирование вывода и пересмотр собственного решения. Такое понимание опирается на положения экспертного отчёта под руководством P. Facione [2]. Для темы химической кинетики оно конкретизируется в доступных наблюдению действиях — выделении данных, выборе зависимости с объяснением её применимости, проверке вычислений и обсуждении ограничений вывода. Четыре критерия ниже являются авторской адаптацией для предметных задач. Анализ проявляется в отборе данных, оценка — в обосновании метода, объяснение — в установлении химических причин, саморегуляция — в проверке и пересмотре вывода. Эти критерии охватывают отдельные проявления критического мышления и требуют проверки содержательной валидности.

Методическая модель связывает наблюдаемые изменения, представления о частицах и символическую запись. Проблема согласования уровней представления химического знания рассматривается в работе A. H. Johnstone [3]. Например, при обсуждении температуры ученик должен связать изменение скорости с распределением энергий частиц, а затем объяснить, какие условия позволяют использовать правило Вант-Гоффа или уравнение Аррениуса.

Опыт разработки интерактивных средств для химического образования представлен, в частности, в работе о симуляциях PhET [4]. В предлагаемой модели цифровое наблюдение включено в задачу, требующую письменного прогноза и объяснения. Изменение параметра становится поводом для проверки идеи ученика. Результат программной модели интерпретируется с учётом заложенных в неё упрощений.

Задача настоящей разработки — конкретизировать работу учителя между наблюдением модели и оценкой ответа ученика. Предлагается связать каждый этап с письменным продуктом — прогнозом, объяснением, расчётом или исправлением вывода. Практический вклад состоит в согласовании этой последовательности с заданиями по кинетике и критериями их проверки. Описанный вариант требует апробации, а сравнение его эффективности с другими методиками выходит за рамки настоящей статьи.

Цифровой ресурс и роль генеративного ИИ

Учебный ресурс «Химиялық реакция жылдамдығы» предназначен для изучения химической кинетики в 10 классе. Его адрес приведён в списке источников [5]. Разработка объединяет интерактивное представление процесса, теоретические пояснения, задания и средства самопроверки. Материалы предусмотрены на казахском, русском и английском языках. При организации занятия учитель выбирает язык и объём материала в соответствии с подготовкой учащихся. Описание относится к публичной версии ресурса, доступной 4 ноября 2026 года. Перед апробацией необходимо сохранить используемую версию отдельно, поскольку содержание сайта может обновляться.

Идея предметного содержания связана с работой Хуантхана Нурсерика над методикой изучения скорости химических реакций. Кеңес Мирас Бейбітұлы предложил использовать возможности ИИ для создания сайта и выполнил его техническую реализацию. Такое сотрудничество позволяет соединить педагогический замысел с программным воплощением. В статье рассматривается применение готового учебного ресурса, созданного при содействии генеративного ИИ.

Интерактивная часть включает модель движения и взаимодействия частиц с изменением параметров, а также графические представления кинетических зависимостей. Тематическое содержание охватывает скорость реакции, столкновения частиц, энергию активации, факторы изменения скорости, кинетические уравнения, температурные зависимости и катализ. Для задач повышенной сложности учитель отдельно определяет необходимые предварительные знания.

Учебная модель частиц используется для качественного обсуждения столкновений и влияния параметров. Её показания нельзя переносить на конкретную химическую систему без установления масштаба времени, единиц параметров и проверки алгоритма. В предлагаемом занятии наблюдение модели служит поводом для формулирования и обсуждения гипотезы, а количественные расчёты выполняются по явно заданным условиям задачи.

В данной работе подтверждено использование генеративного ИИ при создании ресурса. Его потенциальные функции при дальнейшей доработке включают подготовку черновиков объяснений, вариантов заданий и переводов. Конкретные инструменты и операции следует фиксировать в журнале разработки. При подготовке рукописи пересчитаны приведённые в ней числовые примеры. Полная проверка всех переводов, расчётных виджетов и физической адекватности симуляции остаётся отдельной задачей перед апробацией.

При проверке содержания особенно важны несколько разграничений. Показатели степеней в экспериментальном кинетическом уравнении устанавливают по данным или принимают из условия задачи. Для суммарной реакции они не определяются автоматически стехиометрическими коэффициентами. Катализатор рассматривается как средство

изменения пути реакции и её скорости при сохранении термодинамических характеристик исходного и конечного состояний.

Организация учебной деятельности

Предлагаемый цикл строится вокруг одного вопроса или задачи. До работы с ресурсом ученик записывает прогноз и краткое обоснование. Затем изменяет один параметр модели, фиксирует наблюдение и сопоставляет его с прогнозом. После обсуждения механизма изменения скорости он выбирает расчётное соотношение, получает ответ и проверяет его смысл. В заключение ученик отмечает, какие основания позволили сохранить или изменить первоначальное мнение. В таблице 1 приведён проект одного занятия о влиянии температуры. До начала урока учитель открывает нужный экран на доступных устройствах или готовит общую демонстрацию. На этапе расчёта используется задача 1, а при проверке — ошибочный ответ «в девять раз». Время включает переходы и помощь учителя в пределах каждого этапа и уточняется при пробном проведении.

Таблица 1. Проект занятия о влиянии температуры на скорость реакции

Время	Учебное действие	Результат работы ученика
0–5 мин	Учитель задаёт условия задачи 1, ученики прогнозируют изменение скорости	Прогноз и объяснение его основания
5–13 мин	Ученики меняют температуру модели при остальных фиксированных параметрах	Описание изменения столкновений и вопрос к модели
13–21 мин	Учитель обсуждает связь температуры, энергий частиц и эффективных столкновений	Письменное химическое объяснение
21–35 мин	Ученики решают задачу 1, учитель уточняет условия применения правила	Расчёт и обоснование трёх температурных шагов
35–42 мин	Ученики анализируют ответ «в девять раз» и пределы вывода	Исправление ошибки с аргументом
42–45 мин	Ученики сопоставляют вывод с исходным прогнозом	Основание сохранения или изменения прогноза

После урока ресурс может использоваться для самостоятельного повторения и подготовки вопросов. Дистанционное обсуждение в Zoom предлагается как дополнительная форма сопровождения. Учащиеся объясняют выбранное решение и комментируют аргументы друг друга, а учитель задаёт уточняющие вопросы. Длительность и содержание таких встреч следует фиксировать при будущей апробации, поскольку дополнительная помощь может влиять на результат обучения.

В последовательность занятий могут входить шесть тем — определение скорости и чтение графиков, теория столкновений, факторы изменения скорости, кинетическое уравнение, температурные зависимости и катализ с обобщением. Это проект распределения материала. Его необходимо соотнести с конкретной учебной программой, доступным временем и уровнем подготовки класса.

Задания для развития обоснованного рассуждения

Приведённые ниже задания являются методическими примерами. Числовые значения заданы для расчёта. При использовании в классе учитель оценивает не только ответ, но и объяснение выбранного способа решения. Дополнительные вопросы переводят вычислительную задачу в обсуждение условий, доказательств и границ вывода. Задания 1 и 2 рассчитаны на применение заданной зависимости и обсуждение условий. Задание 3 относится к дополнительному уровню и предполагает знакомство с логарифмами, экспонентой и константой скорости. Задание 4 направлено на оценку ошибочного объяснения. Соответствие выбранной программе 10 класса определяется учителем до проведения занятий.

Задание 1. Выбор формулы и проверка результата

Условие. Температурный коэффициент скорости реакции равен 3. Определите изменение скорости при повышении температуры с 20 до 50 °C. Считайте коэффициент постоянным на рассматриваемом интервале, остальные условия — одинаковыми.

Решение. По правилу Вант-Гоффа $v_2/v_1 = \gamma^{((t_2 - t_1)/10)} = 3^3 = 27$. Скорость увеличивается в 27 раз. Ученик должен пояснить, что интервал 30 °C содержит три шага по 10 °C и на каждом шаге скорость умножается на 3.

Вопрос для обсуждения. Другой ученик получил увеличение в девять раз, умножив 3 на 3. Объясните ошибку и предложите проверку. Ожидаемое рассуждение — последовательные изменения имеют множители 3 × 3 × 3. Правило используется как приближённое соотношение для заданного интервала, где γ принимается постоянным.

Задание 2. Анализ условия задачи о времени реакции

Условие. При 50 °C достижение заданной степени превращения занимает 16 минут. Температурный коэффициент равен 2. Оцените время достижения той же степени превращения при 80 °C. В расчётной модели считаем, что при каждой степени превращения скорость увеличивается в одинаковое число раз, а исходный состав и механизм реакции сохраняются. Тогда время достижения выбранной степени превращения сокращается во столько же раз.

Решение. Отношение скоростей равно $2^3 = 8$, поэтому $\tau_2 = 16/8 = 2$ мин. Проверка показывает, что ускорение процесса соответствует уменьшению времени. В ответе необходимо сохранить оговорку об одинаковой степени превращения и принятой зависимости времени от скорости.

Вопрос для обсуждения. Достаточно ли сообщения «реакция стала быстрее», чтобы вычислить время её окончания? Ученик должен назвать недостающие сведения — количественное изменение скорости, критерий окончания и сопоставимость условий. Такое уточнение учит проверять полноту условия до вычислений.

Задание 3. Сравнение температурных зависимостей

Условие. Энергия активации равна 50 кДж/моль. Найдите отношение констант скорости при 298 и 308 К, считая энергию активации и предэкспоненциальный множитель постоянными на этом интервале. Сравните результат с оценкой по правилу Вант-Гоффа при γ = 2 для того же изменения температуры.

Решение. Обозначим $k_1 = k(298\ К)$, $k_2 = k(308\ К)$. По уравнению Аррениуса $\ln(k_2/k_1) = (50\,000/8{,}314) \times (1/298 - 1/308) \approx 0{,}65523$, поэтому $k_2/k_1 \approx 1{,}92558 \approx 1{,}93$. Энергия активации переведена из 50 кДж/моль в 50 000 Дж/моль, R = 8,314 Дж/(моль·К). Оценка с γ = 2 для повышения температуры на 10 градусов даёт множитель 2. Относительное превышение этой оценки над результатом по Аррениусу равно $(2 - 1{,}92558)/1{,}92558 \times 100\% \approx 3{,}86\%$, или 3,9% при округлении до десятых.

Вопрос для обсуждения. Можно ли на основании этого различия объявить одну из формул неверной? Для обоснованного ответа ученик должен сопоставить исходные

предположения. Значение γ = 2 является принятой оценкой, а выражение Аррениуса использует заданную энергию активации. Различие результатов показывает роль параметров и приближений. Для сравнения именно скоростей дополнительно нужны одинаковые концентрации и сохранение кинетического уравнения. Значение γ = 2 здесь задано отдельно и не выведено из принятой энергии активации. Поэтому сопоставление иллюстрирует чувствительность оценки к исходным предположениям.

Задание 4. Оценка ошибочного объяснения

Условие. В учебном объяснении сказано, что катализатор ускоряет реакцию, поскольку увеличивает среднюю кинетическую энергию частиц при неизменной температуре. Оцените утверждение и исправьте его, используя энергетическую диаграмму.

Ожидаемое объяснение. При неизменной температуре повышение средней кинетической энергии не является причиной каталитического ускорения. Катализатор обеспечивает иной механизм с более низким эффективным энергетическим барьером. На диаграмме следует сопоставить пути реакции и показать одинаковые энергетические уровни исходных веществ и продуктов. Для обратимого процесса катализатор ускоряет достижение равновесия, сохраняя его положение при заданной температуре.

Задание можно использовать при обсуждении специально подготовленного ошибочного текста, похожего на ответ генеративной модели. Ученику предлагается выделить неверное утверждение, объяснить основание исправления и сформулировать собственный ответ. Источник ошибки в данном случае задан в учебных целях.

Критерии оценки и проект апробации

Для наблюдения за ходом рассуждения предлагается аналитическая рубрика из четырёх критериев К1–К4 (табл. 2). Каждый критерий оценивается от 0 до 2 баллов. Проверяющий отмечает конкретный фрагмент ответа, соответствующий дескриптору. Ошибка в одном критерии не должна автоматически снижать все остальные оценки. Максимум 8 баллов применяется только к комплексной задаче, в которой явно запрошены все четыре действия.

Таблица 2. Проект рубрики оценки рассуждений

Критерий	0 баллов	1 балл	2 балла
К1 Анализ данных	Пропущено условие, без которого решение неверно	Основные величины выделены, но одно существенное допущение пропущено	Выделены нужные величины и существенные допущения, указана их роль
К2 Обоснование метода	Выбрана неприменимая зависимость или выбор отсутствует	Зависимость верна, но её связь с условиями не объяснена	Названа зависимость и объяснено, почему условия позволяют её применить
К3 Химическое объяснение	Причина изменения скорости объяснена неверно или не указана	Направление изменения названо верно, но причинная связь неполна	Выстроена химически корректная причинная цепочка для рассматриваемого фактора
К4 Проверка вывода	Проверка отсутствует или состоит в повторении ответа	Выполнена одна содержательная проверка ответа	Использованы два независимых основания проверки, при необходимости исправлен вывод

Рубрика предназначена для оценки рассуждений в задачах по химической кинетике. Её валидность и воспроизводимость оценивания предстоит изучить. Общий балл химического теста и балл по этой рубрике следует анализировать раздельно, поскольку они характеризуют разные стороны выполнения работы.

Рубрика применяется с учётом содержания задания. В заданиях 1 и 2 исходно оцениваются К1, К2 и К4, максимум — 6 баллов. Чтобы оценивать К3, добавляется вопрос о связи температуры с энергиями частиц и долей эффективных столкновений. В задании 3 без такого вопроса также оцениваются К1, К2 и К4. В задании 4 оцениваются К3 и К4, максимум — 4 балла, причём для К4 ученик должен сопоставить исправленное объяснение с двумя признаками диаграммы. Итоговые суммы заданий с разными максимумами непосредственно не сравниваются.

Условный пример применения рубрики относится к заданию 1, дополненному вопросом о частицах и требованием проверить ответ двумя способами. Он составлен для пояснения критериев и не является результатом реального ученика. Ответ — «Температура выросла на 30 °C, это три шага по 10 °C. При постоянном γ = 3 скорость увеличится в 3 × 3 × 3 = 27 раз. Выбираю правило Вант-Гоффа, потому что коэффициент задан и принят постоянным. При нагревании увеличивается доля частиц, способных преодолеть энергетический барьер. Ответ больше единицы, что согласуется с ускорением. Ещё проверю последовательно — 3, 9 и 27 раз относительно исходной скорости».

Оценка условного ответа составляет К1 — 2 балла за выделение интервала и допущения, К2 — 2 за обоснование зависимости, К3 — 2 за объяснение через энергию частиц, К4 — 2 за проверку направления изменения и независимый пошаговый пересчёт. Всего 8 баллов. Ответ «27 раз по формуле» при отсутствии дальнейших пояснений не подтверждает все четыре действия. Для К2 он соответствует 1 баллу, для остальных критериев доказательств в записи недостаточно. Устные пояснения учитываются только при заранее установленном и одинаковом для всех порядке их фиксации.

Перед апробацией два проверяющих должны независимо оценить набор учебных примеров, обсудить расхождения и уточнить дескрипторы. На реальных работах необходимо отдельно оценить согласованность проверяющих. Основным планируемым показателем может стать изменение баллов по критериям на сопоставимых комплексных заданиях, а правильность вычислений следует учитывать дополнительно. Критерии, сроки оценивания и правила обработки пропусков закрепляются до сбора данных.

На следующем этапе планируется апробация в доступных для исследования учебных группах. До её начала необходимо определить состав участников, согласовать процедуру со школой и оформить необходимые согласия. Численность выборки и сроки будут отражаться по фактически проведённой работе. Предполагается подготовить входные и итоговые задания сопоставимой сложности и заранее закрепить критерии оценивания.

Для проверки результата целесообразно сохранять обезличенные ответы и баллы по каждому критерию, учитывать посещаемость, время работы с ресурсом и объём помощи учителя. Второй проверяющий позволит оценить согласованность выставления баллов. При небольшой группе следует уделить внимание изменениям в аргументации отдельных учащихся и избегать широких обобщений.

Если будет организовано сравнение групп, необходимо описать исходную подготовку, язык обучения, содержание занятий и условия доступа к помощи. Различия между готовыми классами ограничивают причинную интерпретацию. Анализ должен учитывать, что сайт, самостоятельная практика и дистанционное сопровождение могут одновременно влиять на учебную деятельность.

Обсуждение и заключение

Методический вклад разработки заключается в соединении цифровой визуализации с требованием обосновывать решение. Учителю предлагается последовательность действий, примеры вопросов и критерии, которые делают рассуждение ученика предметом наблюдения. Сайт служит средством организации этой работы, а роль генеративного ИИ связана с подготовкой и совершенствованием цифрового содержания.

Работа ограничена этапом методического проектирования. Представленные задания и рубрика требуют апробации, а доступность отдельных тем повышенной сложности должна быть проверена применительно к конкретному классу. Из содержания разработки нельзя вывести величину ожидаемого прироста баллов или гарантировать развитие критического мышления.

Предложенная модель позволяет выстроить изучение химической кинетики вокруг прогноза, объяснения, расчёта и проверки вывода. Она задаёт основу для дальнейшего магистерского исследования, в котором можно проверить качество аргументации учащихся на сложных задачах. Следующий этап включает уточнение цифрового ресурса, согласование процедуры апробации и сбор реальных учебных материалов по заранее установленным критериям.

Сведения о подготовке работы

Финансирование. Внешнее финансирование разработки и подготовки статьи отсутствует.

Статус исследования. Статья представляет методическую разработку и проект её последующей проверки. Количественные результаты педагогического эксперимента в настоящей работе не представлены. Согласование будущего исследования и оформление согласий относятся к подготовке апробации.

Использование искусственного интеллекта. Генеративный ИИ применялся при создании цифрового учебного ресурса. При подготовке этой редакции рукописи ChatGPT использовался для структурирования и редактирования текста, уточнения методических формулировок и подготовки английской аннотации. Содержательные положения и окончательная редакция подлежат проверке авторами.

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DEVELOPING UNIVERSAL LEARNING ACTIVITIES IN PRIMARY SCHOOL STUDENTS THROUGH A FUNCTIONAL INSTRUCTIONAL MODEL

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Abstract

This article proposes a functional instructional model for developing universal learning activities in primary school students. These activities are understood as transferable processes that enable children to set learning goals, select strategies, cooperate with others, and evaluate their progress. The model connects learning objectives, task selection, classroom interaction, and formative assessment within a recurring instructional cycle. It combines teacher modelling, guided practice, collaborative work, and individual reflection. Particular attention is paid to selecting tasks that require students to explain their reasoning and apply familiar strategies in new situations. A classroom example illustrates how the model can be incorporated into primary science lessons. The article is conceptual and does not report experimental findings. It outlines observable indicators and a research design for evaluating the model in classroom practice.

Keywords: primary education, universal learning activities, instructional model, self-regulated learning, formative assessment, learning tasks.

Introduction

Primary education provides the foundation for how children approach learning. Completing an exercise correctly is one outcome of a lesson, but it does not necessarily show whether a student understands the task, can explain a decision, or knows how to overcome a difficulty. Instruction therefore needs to address the processes through which children organise and evaluate their work.

In this article, universal learning activities refer to learning actions that can be used across subjects, including planning, comparing information, explaining reasoning, monitoring understanding, and evaluating results. Their transfer between subjects should be supported through instruction rather than assumed. A child who checks a calculation may still need help learning how to check an interpretation of a reading passage.

The purpose of this article is to propose a functional instructional model that connects these activities with everyday classroom tasks. The model is intended to help teachers identify what students should learn to do independently and determine which forms of support they need.

Theoretical Background

The proposed model draws on research into self-regulated learning, formative assessment, and the gradual release of responsibility. Panadero (2017) describes self-regulated learning as involving cognitive, metacognitive, motivational, behavioural, and emotional processes. This perspective suggests that classroom instruction should address how students plan and monitor their learning alongside subject knowledge.

Black and Wiliam (1998) examine how classroom assessment can contribute to learning. Within the proposed model, assessment is used to identify a learner's next step: for example,

whether a child needs to reconsider a strategy, provide evidence, or revise an explanation. Feedback must be followed by an opportunity to act on it.

Fisher and Frey's (2008) instructional framework provides a basis for organising support through teacher demonstration, guided instruction, collaborative learning, and independent work. These arrangements help structure the transition towards greater student responsibility.

The present article brings these perspectives together in a conceptual model. It does not claim that their combination has already been validated or that the proposed sequence constitutes a new theory of learning.

Structure of the Functional Instructional Model

The model links five functions: identifying a learning goal, selecting a task, organising support, monitoring performance, and reflecting on transfer. Each function addresses a practical instructional question.

First, the teacher identifies both a subject objective and a learning-process objective. In mathematics, students may learn to compare quantities while also learning to explain why a comparison strategy is appropriate. Expressing the second objective in accessible language helps children recognise what successful learning involves.

Second, the teacher selects a task that makes the intended learning action observable. Tasks should require a meaningful decision, permit explanation, and provide evidence that students can use to check their answers. Suitable formats include comparing alternative solutions, identifying an error, sorting objects according to a justified rule, and choosing evidence for a conclusion. Tasks should remain manageable in relation to students' prior knowledge and language skills.

Third, the teacher organises support. A short demonstration can make an otherwise hidden thinking process visible. Guided practice then gives students an opportunity to use the process with prompts. Pair work allows them to compare explanations, while individual work shows what each learner can accomplish. Support should respond to observed difficulties; students may need to return to guided practice after attempting a task independently.

Fourth, the teacher monitors both the answer and the process used to produce it. Questions such as "How did you decide?" and "What could you check?" reveal information that a correct response alone cannot provide. Students should receive time to revise their work after feedback.

Finally, reflection connects the completed task with future learning. Students identify a useful strategy, explain when it helped, and consider where else it might apply. The teacher can subsequently introduce a related task in another subject to examine whether students recognise and use that strategy.

Classroom Application

A primary science lesson on material properties illustrates the model. Students are asked to investigate which available material would be suitable for protecting a paper object from water. The subject objective concerns material properties; the learning-process objective concerns planning a comparison and using evidence to justify a choice.

Before testing, children predict an outcome and suggest how the materials could be compared fairly. The teacher demonstrates how to record an observation without providing the final answer. Working in pairs, students test the materials, record what happens, and discuss whether their initial predictions were supported.

Each student then writes or orally presents an individual recommendation. The teacher asks for evidence and invites revision where an explanation relies only on preference. A short reflection asks students which part of their plan helped them reach a conclusion.

This example is a proposed teaching scenario, not a report of an implemented intervention. Its purpose is to show how subject learning and transferable learning actions can be addressed within the same task.

Assessment and Further Research

Evaluation should examine specific behaviours rather than assign a single broad label such as “independent learner”. Relevant indicators include stating a goal, selecting a strategy, explaining a choice, checking an answer, and revising work after feedback. Observation records, student work, and brief interviews can provide complementary evidence.

A future classroom study could compare the proposed model with usual instruction using initial, final, and delayed assessments. Tasks should include familiar activities and new situations to distinguish practice effects from transfer. Differences in prior attainment, language proficiency, and teacher implementation should be considered when interpreting results.

Conclusion

The proposed model offers a way to incorporate universal learning activities into ordinary primary lessons. Its practical focus is the relationship between a learning objective, an observable student action, and appropriate teacher support. Classroom research is needed to establish whether repeated use strengthens students’ independent performance and their ability to apply learning strategies across subjects.

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PEDAGOGICAL STRATEGIES FOR DEVELOPING CRITICAL THINKING AMONG PRE-SERVICE TEACHERS THROUGH THE USE OF GENERATIVE ARTIFICIAL INTELLIGENCE

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Abstract

The integration of generative artificial intelligence into higher education has raised questions about its relationship with students' critical thinking and the pedagogical conditions under which these technologies are used. This study examines the associations between reflective GenAI use, perceived pedagogical guidance, and self-reported critical thinking competencies among pre-service teachers in Kazakhstan. A quantitative cross-sectional survey was conducted between September and October 2026, involving 293 students from five higher education institutions. The research instrument comprised 20 items organized into five scales measuring reflective GenAI use, passive reliance on AI-generated responses, digital competence, pedagogical guidance, and critical thinking. Data were analysed using descriptive statistics, Cronbach's alpha, Spearman's rank-order correlations, and ordinary least squares regression. The scales demonstrated acceptable internal consistency (α = 0.803–0.856). Reflective GenAI use was positively associated with self-reported critical thinking (ρ = 0.542, $p < .001$), while perceived pedagogical guidance was positively associated with reflective AI-use practices (ρ = 0.427, $p < .001$). Both relationships remained statistically significant after adjustment for selected individual characteristics. Passive reliance on AI-generated responses was negatively associated with critical thinking (ρ = −0.311, $p < .001$), whereas the frequency of GenAI use was not a significant independent predictor in the adjusted regression model. The findings suggest that students' reported critical thinking is more closely associated with the cognitive strategies accompanying AI use than with its frequency. The study contributes to research on AI-supported teacher education by distinguishing reflective engagement from passive reliance and identifying perceived pedagogical guidance as a correlate of students' evaluative learning practices. The results support the consideration of instructional approaches that encourage independent verification, critical evaluation, and reasoned interpretation of AI-generated information.

Keywords: generative artificial intelligence; critical thinking; pre-service teachers; reflective AI use; pedagogical guidance; teacher education; Kazakhstan.

Introduction

The integration of generative artificial intelligence (GenAI) into higher education has introduced new possibilities for organizing learning activities, constructing knowledge, and

developing students' intellectual competencies. Unlike earlier educational technologies, which primarily facilitated access to information and supported the delivery of instructional materials, contemporary generative AI systems can produce explanations, formulate arguments, generate alternative interpretations, and simulate dialogue in response to complex academic questions. These capabilities have implications for teacher education, where the development of professional competence requires not only the acquisition of disciplinary knowledge but also the ability to evaluate information, justify pedagogical decisions, and reflect critically on instructional practices. Kasneci et al. (2023) argue that large language models offer opportunities for personalized learning and educational support while simultaneously introducing challenges associated with misinformation, reliability, and the potential weakening of independent cognitive engagement. The educational significance of generative AI cannot, however, be determined solely by its technological capabilities. Its contribution to learning depends on the purposes for which students employ these systems, the cognitive demands embedded in educational tasks, and the extent to which instructors encourage independent reasoning. Generative AI may support students in examining competing explanations, identifying weaknesses in arguments, and reconsidering initial assumptions. Conversely, when students use automatically generated responses as substitutes for independent analysis, the technology may reduce opportunities to practise the intellectual operations associated with critical thinking. Tlili et al. (2023) emphasize that the educational application of conversational AI involves both pedagogical opportunities and concerns regarding the reliability of generated information, academic integrity, and students' engagement with learning processes. These considerations are particularly relevant to pre-service teacher education. Future teachers are expected to develop the capacity to assess the credibility of information, interpret educational evidence, evaluate competing pedagogical approaches, and make reasoned instructional decisions. Their engagement with generative AI therefore has implications beyond their immediate academic performance. The practices they acquire during university training may subsequently influence how they organize classroom activities, evaluate students' work, and introduce digital technologies into school education. Research on artificial intelligence literacy suggests that effective engagement with AI requires an integrated set of competencies encompassing conceptual understanding, practical application, critical evaluation, and ethical awareness (Ng et al., 2021). Accordingly, preparing future teachers to use generative AI involves developing their ability to interrogate algorithmically generated information rather than merely increasing their familiarity with digital tools.

The relationship between generative AI and critical thinking has become an important area of contemporary educational research. Critical thinking is generally associated with the capacity to analyze information, evaluate evidence, identify assumptions, construct justified conclusions, and regulate one's own reasoning. Within AI-supported learning environments, these processes acquire additional complexity because students must distinguish between plausible linguistic formulations and empirically substantiated knowledge. A coherent AI-generated explanation may appear authoritative even when it contains factual inaccuracies, unsupported generalizations, or misleading interpretations. The systematic review conducted by Labadze et al. (2023) demonstrates that educational chatbots can support learning through explanations, feedback, and individualized assistance, although their effective integration requires attention to technological limitations and pedagogical conditions. Recent empirical syntheses further suggest that the educational outcomes associated with generative AI depend on how the technology is incorporated into instructional activities. Deng et al. (2025), in a systematic review and meta-analysis of experimental studies, report positive overall effects of ChatGPT-supported interventions on academic performance and higher-order thinking outcomes. Nevertheless, the authors identify methodological limitations concerning assessment practices and the measurement of sustained learning effects. These findings indicate that improvements in

educational performance should not automatically be interpreted as evidence of corresponding improvements in independent reasoning. The distinction is particularly important in teacher education, where students must develop transferable analytical competencies that remain applicable beyond AI-assisted assignments. From a pedagogical perspective, generative AI can be incorporated into learning through different forms of cognitive engagement. One approach emphasizes efficiency-oriented practices, including generating summaries, producing preliminary answers, and completing routine academic tasks. Another approach involves reflective and evaluative practices, such as questioning AI-generated claims, comparing alternative explanations, verifying information against independent sources, and revising arguments on the basis of evidence. Although both approaches involve interaction with the same technological systems, they differ in the intellectual demands placed on students. The systematic mapping review by Yusuf et al. (2024) identifies pedagogical enhancement, academic assistance, and professional development among the major applications of generative AI, while also drawing attention to limitations in experimental research and the examination of educational practices across different cultural contexts. The distinction between productive cognitive support and excessive reliance on automated outputs raises a broader question concerning the organization of learning in technology-rich educational environments. Generative AI may function as a resource for intellectual exploration when students remain responsible for evaluating information and constructing conclusions. However, its pedagogical value becomes more uncertain when students transfer essential analytical operations to automated systems. This concern is consistent with the human-centred approach advanced by Miao and Holmes (2023), which emphasizes the need to preserve human agency, ethical responsibility, and meaningful learning within AI-supported educational environments. For teacher education institutions, the challenge is therefore not simply to introduce generative AI into university curricula but to establish pedagogical conditions under which its use contributes to independent judgment and reflective professional learning.

Research Gap

Despite the expansion of research on generative AI in higher education, several limitations remain in understanding its relationship with critical thinking among pre-service teachers. A substantial proportion of the literature examines students' attitudes towards AI, perceptions of its usefulness, patterns of adoption, and general educational outcomes. Although these dimensions provide valuable information about technological integration, they do not sufficiently explain how different strategies of AI use are associated with students' analytical and evaluative competencies. In particular, the distinction between reflective engagement with AI-generated content and reliance on automatically produced answers requires further empirical examination (Labadze et al., 2023; Yusuf et al., 2024). A second limitation concerns the relationship between pedagogical organization and students' cognitive engagement with generative AI. Existing research has established that AI tools can provide feedback, explanations, and instructional assistance, yet the presence of these technological functions does not necessarily indicate that students employ them in intellectually productive ways. The extent to which students critically evaluate generated information may depend on instructional expectations, opportunities for reflection, and the pedagogical strategies adopted by university instructors. Consequently, research needs to distinguish between the availability of AI-supported learning resources and the educational practices through which students are encouraged to question, verify, and interpret their outputs (Kasneci et al., 2023; Tlili et al., 2023). A further gap concerns the institutional and geographical contexts in which generative AI is studied. International reviews indicate that research on AI-supported education encompasses diverse disciplinary settings, but culturally situated investigations of pedagogical practices and teacher preparation remain comparatively limited (Yusuf et al., 2024). Within this broader research landscape, Kazakhstan provides a relevant setting for examining how pre-service teachers engage with generative AI during their university studies.

However, findings obtained in other educational systems cannot be assumed to describe the relationship between AI use and critical thinking among students enrolled in Kazakhstan's teacher education programmes. Context-specific empirical evidence is therefore needed to examine whether reflective AI-use practices and pedagogical guidance are associated with students' reported critical thinking competencies. The present study addresses these gaps by distinguishing between the frequency of generative AI use and the cognitive strategies through which students interact with AI-generated information. Rather than treating technological adoption as an inherently beneficial educational outcome, the study examines whether reflective engagement with generative AI is associated with critical thinking and whether pedagogical guidance is related to students' adoption of such practices. This approach positions critical thinking as an educational competence that must be examined in relation to specific learning behaviours and instructional conditions.

The research object is the educational use of generative artificial intelligence among pre-service teachers enrolled in higher education institutions in Kazakhstan.

The research subject is the relationship between reflective strategies of generative AI use, pedagogical guidance, and self-reported critical thinking competencies among pre-service teachers.

The aim of the study is to examine how reflective engagement with generative AI and pedagogical guidance are associated with critical thinking-related learning practices among pre-service teachers in Kazakhstan. To address this aim, the study is designed around a quantitative survey framework involving 293 pre-service teachers. The proposed analytical model differentiates reflective AI use, passive reliance on AI-generated responses, perceived pedagogical guidance, and self-reported critical thinking. These constructs allow the investigation to move beyond descriptive measures of AI adoption and consider the cognitive and instructional conditions associated with students' engagement with generative technologies.

Research Hypotheses. Drawing on the literature concerning AI literacy, critical thinking, and pedagogically structured technology use, the study proposes two hypotheses.

H1. Reflective use of generative artificial intelligence is positively associated with self-reported critical thinking competencies among pre-service teachers.

This hypothesis assumes that students who regularly verify AI-generated information, compare alternative explanations, question automated responses, and independently evaluate arguments are more likely to report stronger critical thinking competencies than those who engage less frequently in such practices.

H2. Perceived pedagogical guidance in the use of generative artificial intelligence is positively associated with reflective AI-use practices among pre-service teachers.

This hypothesis assumes that students who receive instructional guidance concerning the evaluation, verification, and responsible interpretation of AI-generated information are more likely to adopt reflective strategies when using generative AI for academic purposes.

The theoretical framework integrates three complementary perspectives: constructivist approaches to learning, self-regulated learning, and artificial intelligence literacy. Together, these perspectives provide a conceptual basis for explaining why the educational implications of generative AI depend on students' cognitive engagement and the instructional conditions under which the technology is used. The first perspective draws on contemporary constructivist interpretations of AI-supported learning, according to which knowledge development requires active engagement with information rather than its passive reception. From this standpoint, generative AI becomes pedagogically relevant when students use generated explanations as objects of inquiry, comparison, and critical examination. Its contribution to learning therefore depends less on the availability of automatically produced answers than on the cognitive activities through which students interpret and evaluate them. Kasneci et al. (2023) discuss the educational

opportunities of large language models in relation to individualized assistance, learning support, and the need to maintain critical engagement with generated information. This perspective supports the assumption that reflective interaction with generative AI may be associated with stronger critical thinking competencies. The second perspective concerns self-regulated learning, particularly the processes through which students monitor their understanding, evaluate information, and adjust their learning strategies. In generative AI-supported environments, self-regulation includes recognizing the limitations of automated explanations, determining when independent verification is necessary, and maintaining responsibility for academic judgments. Students who engage in these processes may use generative AI as a resource for evaluating their reasoning rather than as a substitute for it. The concerns regarding reliability, overreliance, and responsible educational use discussed by Tlili et al. (2023) and Miao and Holmes (2023) provide a contemporary basis for examining these regulatory practices. Within the present study, reflective AI use is therefore conceptualized as a set of learning behaviours involving verification, comparison, and critical evaluation. The third perspective is grounded in the concept of AI literacy. Ng et al. (2021) conceptualize AI literacy through interconnected dimensions involving understanding AI, applying AI technologies, evaluating their outputs, and addressing ethical considerations. This framework is particularly relevant to teacher education because future teachers require not only operational familiarity with AI systems but also the ability to assess their educational suitability and limitations. AI literacy thus provides a conceptual connection between technological competence and the critical evaluation of algorithmically generated information. In the present study, this perspective informs the distinction between general engagement with generative AI and reflective practices requiring independent intellectual judgment. These perspectives are integrated through a conceptual model in which reflective AI use is expected to be positively associated with self-reported critical thinking, while pedagogical guidance is expected to be positively associated with reflective AI-use practices. The model does not assume that generative AI independently produces improvements in cognitive competence. Instead, it treats students' learning strategies and instructional experiences as relevant conditions for understanding differences in their reported critical thinking. Given the cross-sectional design, the proposed relationships are interpreted as associations rather than causal effects.

The theoretical significance of the study lies in its differentiation of generative AI adoption from reflective cognitive engagement. Existing discussions frequently consider the educational potential of generative AI in terms of accessibility, efficiency, individualized assistance, and academic performance. The present study extends this discussion by examining the learning strategies through which students interact with AI-generated information and by relating these strategies to self-reported critical thinking competencies. By integrating constructivist learning, self-regulation, and AI literacy, the research provides a framework for investigating generative AI as a component of pedagogically organized intellectual activity rather than merely as an educational technology. The study also contributes to research on teacher education by examining the relationship between perceived instructional guidance and reflective AI use. This distinction is theoretically relevant because the educational outcomes associated with technological tools cannot be separated from the practices through which students are encouraged to use them. The proposed framework therefore allows pedagogical guidance to be considered as an institutional and instructional dimension of AI-supported learning, complementing individual-level explanations centred on students' technological familiarity and attitudes.

The practical significance concerns the design of teacher education programmes in Kazakhstan. The proposed findings may inform the development of instructional activities that encourage pre-service teachers to evaluate AI-generated explanations, compare competing arguments, verify sources, and justify pedagogical decisions. They may also provide a basis for reviewing how university instructors communicate expectations concerning responsible AI use

and independent academic reasoning. Such applications are consistent with international recommendations emphasizing human agency, critical evaluation, and pedagogically appropriate integration of generative AI (Miao & Holmes, 2023). At the same time, the interpretation of the study will depend on the methodological characteristics of the empirical data. A cross-sectional survey based on self-reported measures can identify associations between AI-use strategies, pedagogical guidance, and perceived critical thinking, but it cannot establish whether these practices produce measurable improvements in cognitive performance. The study should therefore be understood as an investigation of reported competencies and educational practices, with subsequent experimental or longitudinal research required to assess changes in critical thinking over time.

Literature Review

Recent research on generative artificial intelligence in higher education has increasingly examined the relationship between AI-supported learning and higher-order cognitive competencies. Walter (2024) conceptualizes AI literacy, prompt engineering, and critical thinking as interconnected dimensions of contemporary educational practice, arguing that effective engagement with AI requires learners to understand both the possibilities and epistemic limitations of automated systems. Empirical evidence, however, suggests that the relationship between AI use and cognitive development is not uniform. In an experimental study involving 125 undergraduate students in Ghana, Essel et al. (2024) examined differences in critical, creative, and reflective thinking between students using ChatGPT and those relying on conventional information resources. Their findings indicated measurable differences in cognitive outcomes associated with the instructional use of ChatGPT. A broader meta-analysis by Chen and Cheung (2025), synthesizing 57 studies, identified positive effects of generative AI on higher-order thinking but found no statistically significant overall effect on metacognition. This distinction suggests that improvements in task performance and analytical outcomes do not necessarily coincide with improvements in students' capacity to monitor and regulate their reasoning. Similarly, Zhao et al. (2025), drawing on 29 experimental and quasi-experimental studies, reported a moderate positive effect of generative AI on higher-order thinking, with stronger outcomes associated with problem-solving and critical thinking than with creativity. Their analysis also indicated that intervention duration and self-regulated learning influenced the observed effects. Taken together, these studies suggest that the cognitive implications of generative AI should be examined through the organization of learning activities rather than inferred from technology use alone.

The distinction between reflective engagement and cognitive dependence has received particular attention in recent investigations. Sardi et al. (2025), reviewing 38 studies, found that generative AI frequently supported self-regulated learning through personalized feedback, metacognitive assistance, and opportunities for reflection. Nevertheless, the authors also identified concerns that excessive reliance on automated responses could limit students' independent intellectual engagement. Comparable conclusions emerge from the systematic review by Liu et al. (2025), which examined 15 studies of generative AI and critical thinking in English as a foreign language education. Their synthesis demonstrated that AI-supported activities may facilitate analytical reasoning when learners actively evaluate generated content, whereas uncritical acceptance of automated explanations can undermine the educational value of such interactions. Daniel et al. (2025), reviewing 158 studies on academic skills development, similarly identified reported improvements across cognitive, technical, and interpersonal domains, although the heterogeneity of research designs complicates conclusions about the durability of these outcomes. Fischer et al. (2024) provide a complementary perspective by comparing students' accounts of generative AI use with assessors' evaluations of academic assignments. Their findings suggest that students may concentrate on AI-assisted text production without fully engaging in the analytical processes expected within higher education. These findings collectively

indicate that the frequency of AI use is an insufficient indicator of critical thinking. Greater analytical attention should be directed towards the purposes of AI interaction, the verification of generated information, and the degree of independent judgment retained by students.

Research focusing specifically on pre-service teachers introduces an additional dimension because future educators must develop competencies for both their own academic learning and subsequent classroom practice. Bae et al. (2024) investigated pre-service teachers' perceptions of generative AI through discussions conducted in asynchronous online courses. Their findings indicated that exposure to ChatGPT increased participants' awareness and foundational knowledge while reducing anxiety, although relatively few students expressed definite intentions to incorporate the technology into their future teaching. This suggests that technological familiarity does not automatically translate into pedagogical readiness. Dayagbil et al. (2025), examining 515 pre-service teachers in the Philippines, further investigated students' knowledge, perceptions, and experiences of AI-supported educational activities, demonstrating the relevance of teacher preparation as a distinct context for AI integration. From an instructional design perspective, Choi et al. (2024) examined the strengths, weaknesses, opportunities, and threats associated with generative AI in developing educational materials. Their analysis indicates that automated content generation offers instructional possibilities but requires professional evaluation of its pedagogical appropriateness. These studies highlight a conceptual distinction between knowing how to operate generative AI and knowing how to employ it in educationally defensible ways. For future teachers, reflective engagement involves evaluating the accuracy, relevance, and instructional implications of generated content, while pedagogical guidance may help establish the conditions under which such evaluation becomes a regular learning practice.

The literature also provides evidence that structured instructional activities can influence how students evaluate AI-generated information. King and Lopour (2025) developed classroom exercises in biomedical engineering education intended to expose students to the strengths and limitations of ChatGPT in scientific reasoning and writing. Their approach illustrates how deliberately designed tasks can require learners to identify inaccuracies and critically examine automated suggestions instead of accepting them as authoritative. The relevance of instructional organization is also apparent in the findings of Fischer et al. (2024), who demonstrate that the integration of AI into assessment requires reconsideration of how independent reasoning is encouraged and evaluated. At a broader level, the synthesis by Chen and Cheung (2025) identifies variation in educational outcomes according to learner characteristics, instructional arrangements, and contextual conditions. However, evidence from general university populations and discipline-specific interventions cannot be transferred uncritically to teacher education. Moreover, much of the available research examines AI literacy, acceptance, academic performance, or the effects of particular interventions, whereas the relationship between everyday reflective AI-use practices, perceived pedagogical guidance, and self-reported critical thinking remains less clearly established among pre-service teachers. The present study addresses this issue within Kazakhstan's higher education context by examining two theoretically connected relationships: the association between reflective generative AI use and critical thinking competencies, and the association between pedagogical guidance and reflective AI-use practices.

Research Methodology

The study employed a quantitative, cross-sectional research design to examine the relationships between generative artificial intelligence (GenAI) use, perceived pedagogical guidance, and self-reported critical thinking competencies among pre-service teachers in Kazakhstan. Data collection took place between September and October 2026. The research focused on students enrolled in undergraduate teacher education programmes, with particular attention to the ways in which they evaluated AI-generated information, incorporated automated responses into their academic activities, and experienced instructional guidance concerning the

responsible use of generative technologies. A survey-based approach was selected because the research questions concerned individual learning practices, perceived instructional conditions, and differences in self-assessed cognitive competencies. Rather than evaluating the effectiveness of a particular AI intervention, the study examined naturally occurring patterns of GenAI engagement within the context of university education. This distinction was relevant to the proposed hypotheses, which concerned associations between educational practices rather than experimentally established changes in learning outcomes. The analytical framework distinguished reflective GenAI use from passive reliance on AI-generated responses. Reflective use was conceptualized as a set of practices involving independent verification, comparison of explanations, identification of inaccuracies, and reconsideration of personal arguments. Passive reliance referred to the acceptance or reproduction of automatically generated content without substantial independent evaluation. Perceived pedagogical guidance was examined as an instructional dimension potentially associated with students' reflective engagement, while self-reported critical thinking represented the principal outcome variable.

The analytical dataset comprised 293 student records representing five higher education institutions in Kazakhstan offering teacher education programmes: Abai Kazakh National Pedagogical University, Kazakh National Women's Teacher Training University, Margulan Pedagogical University, South Kazakhstan Pedagogical University, and K. Zhubanov Aktobe Regional University. The institutional distribution included 53 students from Abai Kazakh National Pedagogical University (18.1%), 72 from Kazakh National Women's Teacher Training University (24.6%), 58 from Margulan Pedagogical University (19.8%), 62 from South Kazakhstan Pedagogical University (21.2%), and 48 from K. Zhubanov Aktobe Regional University (16.4%). Participants were aged between 18 and 24 years and represented all four years of undergraduate study. The dataset included 75 first-year students (25.6%), 84 second-year students (28.7%), 69 third-year students (23.5%), and 65 fourth-year students (22.2%). Regarding gender, 66 participants were coded as male (22.5%), 224 as female (76.5%), and three as other or undisclosed (1.0%). The respondents represented five fields of teacher preparation: primary education, language education, science, technology, engineering and mathematics (STEM), humanities, and preschool education. This disciplinary distribution provided an opportunity to examine GenAI-related learning practices across different areas of pedagogical preparation. The sample covered students from institutions situated in different geographical areas of Kazakhstan. Nevertheless, the findings should be interpreted within the institutional and demographic characteristics of the surveyed group rather than generalized automatically to the entire population of pre-service teachers in the country.

The research instrument was a structured questionnaire comprising demographic questions, a measure of GenAI-use frequency, and 20 statements organized into five four-item scales. The questionnaire was designed to distinguish between different forms of engagement with generative AI and to examine their relationships with instructional experiences and self-reported cognitive practices. The first scale measured **reflective GenAI use** (REF1–REF4). Its items addressed the verification of AI-generated information through independent sources, comparison of alternative AI-generated explanations, identification of limitations and errors, and the use of AI-generated content to reconsider one's own arguments. Higher scores indicated more frequent endorsement of reflective approaches to AI-supported learning. The second scale assessed **passive reliance on GenAI** (PASS1–PASS4). The statements examined the use of AI-generated answers without substantial modification, acceptance of automated responses without additional verification, delegation of academic tasks to AI instead of independent analysis, and reproduction of AI-generated conclusions in academic work. Higher scores indicated greater reliance on automatically generated content. The third scale measured **self-reported digital competence** (DIG1–DIG4). The items concerned students' perceived ability to formulate effective prompts,

verify factual information in AI-generated responses, recognize technological limitations and potential algorithmic biases, and maintain confidentiality when interacting with generative AI systems. This measure captured perceived competencies rather than performance demonstrated through practical assessment. The fourth scale examined **perceived pedagogical guidance** (PED1–PED4). Participants assessed whether their instructors discussed the limitations of AI, required justification of AI-supported conclusions, encouraged comparisons between AI-generated information and scientific sources, and assigned activities involving critical evaluation of AI-generated content. The scale therefore represented students' perceptions of instructional practices rather than independently observed teaching behaviour. The fifth scale assessed **self-reported critical thinking competencies** (CT1–CT4). Its statements addressed the evaluation of arguments before making decisions, verification of evidence supporting contested claims, consideration of alternative perspectives, and justification of source credibility. These items operationalized critical thinking through students' reported evaluative practices. Consequently, the measure should not be interpreted as a standardized assessment of objectively demonstrated critical thinking ability. All 20 statements were measured using a five-point Likert-type response format ranging from 1 (strongly disagree) to 5 (strongly agree). Composite scores were calculated as the arithmetic mean of the four items belonging to each scale, producing five indicators ranging from 1 to 5. Higher values represented stronger endorsement of the respective construct. In addition to these scales, participants' frequency of GenAI use was represented by a five-category variable ranging from 1 (never) to 5 (daily). Demographic variables included age, gender, year of study, university, and field of teacher preparation. The measurement framework was informed by contemporary research on AI literacy, reflective learning, and the pedagogical integration of generative technologies (Ng et al., 2021; Kasneci et al., 2023; Walter, 2024). The questionnaire operationalized these theoretical concepts through context-specific statements addressing students' reported educational practices.

Data Preparation and Statistical Analysis

The dataset contained 293 observations and no missing values in the recorded variables. The five composite indicators were calculated from their corresponding four-item scales. Prior to hypothesis testing, the internal consistency and dimensional structure of the measures should be examined to determine whether their items provide sufficiently coherent representations of the intended constructs. Descriptive statistics, including frequencies, percentages, means, and standard deviations, were selected to characterize the sample and summarize responses to the questionnaire. Internal consistency should be evaluated using Cronbach's alpha, with additional reliability indicators considered where appropriate. Exploratory factor analysis may be used to examine whether the questionnaire items reproduce the proposed five-dimensional measurement structure. The first hypothesis (H1) concerns the relationship between reflective GenAI use and self-reported critical thinking competencies. This association can be examined through correlation analysis and regression modelling, with the critical thinking composite score treated as the dependent variable and reflective GenAI use as the principal explanatory variable. The second hypothesis (H2) concerns the relationship between perceived pedagogical guidance and reflective GenAI-use practices. For this hypothesis, reflective GenAI use constitutes the dependent variable, while perceived pedagogical guidance serves as the principal explanatory variable. Additional regression specifications may incorporate age, gender, year of study, field of teacher preparation, university affiliation, frequency of GenAI use, passive reliance, and digital competence to examine the robustness of the principal associations. The inclusion of covariates should be guided by the conceptual framework, the distribution of the variables, and diagnostic assessments of the regression models. The interpretation of statistical findings should consider the ordinal origin of the questionnaire items, the properties of the composite scales, and the assumptions underlying the selected analytical procedures. Effect sizes and confidence intervals

should be reported alongside statistical significance tests. Given the cross-sectional and self-reported nature of the data, the analysis can identify statistical relationships but cannot establish causal effects. In particular, an association between reflective AI use and critical thinking does not demonstrate that generative AI improves students' cognitive competencies. Similarly, an association between pedagogical guidance and reflective engagement does not establish the direction of influence between these variables.

Methodological Limitations

Several methodological considerations should inform the interpretation of the study. First, the cross-sectional design does not permit conclusions about changes in critical thinking over time. The institutional coverage and demographic composition of the sample limit the extent to which the results can be generalized to all pre-service teachers in Kazakhstan. These considerations do not preclude an examination of the proposed relationships but establish the boundaries within which the empirical findings should be interpreted.

Results and Discussion

The analytical dataset comprised 293 observations representing pre-service teachers from five higher education institutions in Kazakhstan. The participants differed in their institutional affiliation, year of study, gender, and field of teacher preparation. The distribution of respondents is presented in Table 1.

Table 1. Sociodemographic and educational characteristics of respondents (N = 293)

Characteristics	*n*	*%*
University		
Abai Kazakh National Pedagogical University	53	18.1
Kazakh National Women's Teacher Training University	72	24.6
Margulan Pedagogical University	58	19.8
South Kazakhstan Pedagogical University	62	21.2
K. Zhubanov Aktobe Regional University	48	16.4
Gender		
Male	66	22.5
Female	224	76.5
Other/undisclosed	3	1.0
Year of study		
First year	75	25.6
Second year	84	28.7
Third year	69	23.5
Fourth year	65	22.2
Field of teacher preparation		
Primary education	48	16.4
Language education	59	20.1
STEM education	77	26.3
Humanities education	51	17.4
Preschool education	58	19.8

Note. Percentages may not total exactly 100% because of rounding. Source: Authors' calculations based on the supplied dataset.

Female students accounted for approximately three-quarters of the sample (76.5%), whereas male students represented 22.5%. This distribution should be considered when interpreting the findings, particularly because the study did not employ population-based weighting to adjust for differences in the demographic composition of teacher education programmes. The distribution across years of study was relatively balanced. Second-year students constituted the largest group (28.7%), followed by first-year (25.6%), third-year (23.5%), and fourth-year students (22.2%). The sample also included students from five fields of teacher preparation, with STEM education representing the largest disciplinary category (26.3%). This composition provided variation in educational backgrounds, although it did not establish statistical representativeness at the national level. The frequency distribution indicated that generative AI had become a commonly reported component of students' academic activities. Of the 293 respondents, 82 (28.0%) reported using GenAI daily, while 103 (35.2%) indicated frequent use.



Figure 1. Frequency of generative AI use among pre-service teachers

Note. Percentages are rounded. Source: Authors' calculations based on the supplied dataset.

Another 57 students (19.5%) used these technologies occasionally, 35 (11.9%) rarely, and 16 (5.5%) reported never using them (Figure 1).

Taken together, 63.1% of respondents reported using generative AI either frequently or daily. This finding suggests that automated content-generation systems were familiar to a substantial proportion of the surveyed students. Nevertheless, frequency of use alone provides limited information about the intellectual activities accompanying AI-supported learning. Students may interact with the same technologies for substantially different purposes, ranging from obtaining ready-made answers to evaluating competing explanations and examining the reliability of information. This distinction is central to the present investigation. The analytical model therefore treats the frequency of GenAI use separately from reflective engagement, passive reliance, and perceived digital competence. The internal consistency of the five scales was examined using Cronbach's alpha. All scales demonstrated acceptable reliability, with coefficients ranging from 0.803 to 0.856. Descriptive statistics and reliability estimates are reported in Table 2.

Table 2. Descriptive statistics and internal consistency of the research constructs

Construct	Items	Mean	SD	Cronbach's α
Reflective GenAI use	4	2.999	0.820	0.816
Passive reliance on GenAI	4	3.215	0.758	0.803
Digital competence	4	3.187	0.807	0.825
Pedagogical guidance	4	3.022	0.893	0.856
Self-reported critical thinking	4	3.059	0.805	0.815

The highest mean score was observed for passive reliance on GenAI (M = 3.215, SD = 0.758), followed by digital competence (M = 3.187, SD = 0.807). Reflective GenAI use had a mean score of 2.999 (SD = 0.820), while pedagogical guidance was assessed at 3.022 (SD = 0.893). Self-reported critical thinking demonstrated a mean score of 3.059 (SD = 0.805). The proximity of these mean values to the midpoint of the response scale suggests that the respondents did not uniformly endorse either reflective or passive approaches to GenAI-supported learning. Rather, both types of engagement were present within the surveyed population. The somewhat higher mean for passive reliance warrants attention, although the difference between scale means should not be interpreted as statistically significant without a corresponding paired comparison. Pedagogical guidance demonstrated the highest internal consistency (α = 0.856), indicating relatively coherent responses across items concerning instructors' expectations, verification practices, and critical engagement with AI-generated content. Reflective GenAI use (α = 0.816) and self-reported critical thinking (α = 0.815) also demonstrated acceptable reliability for the subsequent analysis of their relationship. An examination of the overall item correlation matrix produced a Kaiser–Meyer–Olkin measure of sampling adequacy of 0.865. Bartlett's test of sphericity was statistically significant, $\chi^2(190) = 2379.31$, $p < .001$. These results indicate that the inter-item correlations were suitable for factor-analytic investigation. However, they do not independently establish the proposed five-factor structure, which would require examination of factor loadings and dimensionality. Spearman's rank-order correlation coefficients were calculated to examine the associations between the five composite scales. This approach was selected to assess the direction and strength of monotonic relationships while accommodating the ordinal origins of the questionnaire responses (Table 3).

Table 3. Spearman's correlation matrix for the principal research constructs

Construct	1	2	3	4	5
1. Reflective GenAI use	1.000				
2. Passive reliance	−0.243***	1.000			
3. Digital competence	0.305***	0.015	1.000		
4. Pedagogical guidance	0.427***	−0.015	0.063	1.000	
5. Critical thinking	0.542***	−0.311***	0.286***	0.327***	1.000

The strongest positive association was observed between reflective GenAI use and self-reported critical thinking (ρ = 0.542, $p < .001$). Students reporting more frequent verification of AI-generated information, comparison of alternative explanations, and independent evaluation of automated responses also tended to report stronger critical thinking practices. This association was moderate in magnitude and consistent with the theoretical expectation that reflective engagement with generative technologies is related to evaluative learning behaviours. Perceived pedagogical guidance was positively associated with reflective GenAI use (ρ = 0.427, $p < .001$). Students who reported greater instructional emphasis on verifying AI-generated information and justifying academic conclusions also tended to report more reflective interaction with generative AI systems. This result supports the relevance of instructional practices when examining differences in students' approaches to AI-supported learning. A negative association emerged between passive reliance on GenAI and self-reported critical thinking (ρ = −0.311, $p < .001$). Respondents who more strongly endorsed the uncritical acceptance or reproduction of AI-generated answers tended to report lower levels of evaluative and analytical engagement. Passive reliance was also negatively associated with reflective GenAI use (ρ = −0.243, $p < .001$), although the magnitude of this relationship was comparatively modest. Digital competence demonstrated positive associations with reflective GenAI use (ρ = 0.305, $p < .001$) and critical thinking (ρ = 0.286,

p < .001). These relationships suggest that students who perceived themselves as more capable of operating and evaluating AI systems also tended to report stronger reflective and critical practices. Pedagogical guidance was positively associated with critical thinking (ρ = 0.327, p < .001). However, its correlations with passive reliance (ρ = −0.015) and digital competence (ρ = 0.063) were not statistically significant. These findings indicate that perceived instructional guidance was more closely associated with reflective engagement than with students' general perceptions of technological competence or their passive reliance on AI-generated content (Table 4).

The first hypothesis proposed that reflective use of generative artificial intelligence would be positively associated with self-reported critical thinking competencies among pre-service teachers. The correlation analysis identified a statistically significant positive relationship between the two constructs (ρ = 0.542, p < .001). To examine the relationship further, ordinary least squares regression was estimated with critical thinking as the dependent variable and reflective GenAI use as the explanatory variable.

Table 4. Regression analysis of reflective GenAI use and self-reported critical thinking (H1)

Predictor	*B*	*95% CI*	*p*
Constant	1.441	[1.158, 1.725]	< .001
Reflective GenAI use	0.539	[0.447, 0.632]	< .001

Reflective GenAI use was positively associated with critical thinking (B = 0.539, 95% CI [0.447, 0.632], p < .001). A one-point difference in the reflective-use composite score corresponded to an estimated 0.539-point difference in self-reported critical thinking. The model accounted for approximately 30.2% of the observed variance in the outcome variable. To examine whether this association persisted after accounting for other characteristics, an additional regression model included passive reliance, digital competence, frequency of GenAI use, age, and year of study (Table 5).

Table 5. Adjusted regression model predicting self-reported critical thinking

Predictor	*B*	*95% CI*	*p*
Reflective GenAI use	0.436	[0.336, 0.536]	< .001
Passive reliance	−0.222	[−0.327, −0.116]	< .001
Digital competence	0.176	[0.081, 0.272]	< .001
Frequency of GenAI use	−0.049	[−0.119, 0.021]	.169
Age	−0.049	[−0.124, 0.026]	.198
Year of study	0.062	[−0.036, 0.161]	.216

The association between reflective GenAI use and critical thinking remained statistically significant after adjustment (B = 0.436, p < .001). Passive reliance was negatively associated with the outcome (B = −0.222, p < .001), whereas digital competence demonstrated a positive association (B = 0.176, p < .001). In contrast, the frequency of GenAI use was not statistically significant in the adjusted model (p = .169). Neither age nor year of study demonstrated statistically significant independent associations with the critical thinking composite score. The adjusted model accounted for 37.4% of the variance in self-reported critical thinking. These findings provide statistical support for H1 and indicate that reflective engagement remained associated with critical thinking after adjustment for the selected covariates.

The second hypothesis proposed that perceived pedagogical guidance in the use of generative artificial intelligence would be positively associated with reflective AI-use practices. Spearman's correlation analysis demonstrated a statistically significant positive association between pedagogical guidance and reflective GenAI use ($\rho = 0.427$, $p < .001$). A regression model was subsequently estimated to examine the magnitude of this relationship (Table 6).

Table 6. Regression analysis of pedagogical guidance and reflective GenAI use (H2)

Predictor	*B*	*95% CI*	*p*
Constant	1.782	[1.482, 2.083]	< .001
Pedagogical guidance	0.403	[0.308, 0.498]	< .001

Pedagogical guidance was positively associated with reflective GenAI use (B = 0.403, 95% CI [0.308, 0.498], $p < .001$). The model accounted for approximately 19.2% of the variance in reflective-use scores. An adjusted model was estimated to determine whether this association persisted after controlling for passive reliance, digital competence, frequency of GenAI use, age, and year of study.

Table 7. Adjusted regression model predicting reflective GenAI use

Predictor	*B*	*95% CI*	*p*
Pedagogical guidance	0.381	[0.297, 0.465]	< .001
Passive reliance	−0.274	[−0.378, −0.170]	< .001
Digital competence	0.312	[0.215, 0.410]	< .001
Frequency of GenAI use	0.040	[−0.035, 0.115]	.299
Age	−0.032	[−0.104, 0.040]	.388
Year of study	0.027	[−0.074, 0.128]	.597

The positive association between pedagogical guidance and reflective GenAI use remained statistically significant (B = 0.381, $p < .001$). Digital competence was also positively associated with reflective engagement (B = 0.312, $p < .001$), whereas passive reliance demonstrated a negative association (B = −0.274, $p < .001$). The frequency of GenAI use, age, and year of study were not statistically significant in this model. The explanatory variables collectively accounted for approximately 35.5% of the variance in reflective GenAI use. These results provide statistical support for H2. They indicate that students reporting stronger pedagogical guidance also tended to demonstrate higher levels of reflective engagement with AI-generated information, even after adjustment for the selected individual characteristics. Both hypotheses received statistical support. Reflective GenAI use demonstrated a moderate positive association with self-reported critical thinking, while perceived pedagogical guidance was positively associated with reflective GenAI-use practices. The relationships remained statistically significant in regression models incorporating selected individual-level covariates.

The findings contribute to the literature on generative artificial intelligence in teacher education by distinguishing between the frequency of technology use and the cognitive practices through which students engage with AI-generated information. The results suggest that students' reported critical thinking is more closely associated with reflective engagement than with the frequency of AI use alone. This distinction is relevant to ongoing discussions about whether generative AI functions as a resource for independent reasoning or encourages dependence on

automatically produced academic content. The positive association between reflective GenAI use and self-reported critical thinking is consistent with the conceptual position advanced by Walter (2024), who emphasizes the relationship between AI literacy, critical evaluation, and responsible engagement with automated systems. It also corresponds to the broader educational concerns identified by Kasneci et al. (2023), particularly the need to preserve independent intellectual judgment when students encounter plausible but potentially unreliable AI-generated explanations. The present results add context-specific evidence from pre-service teachers in Kazakhstan, showing that verification, comparison, and reconsideration of AI-generated arguments are associated with students' reported analytical practices. Nevertheless, this association should not be interpreted as evidence that generative AI independently improves critical thinking. Students who already possess stronger evaluative dispositions may be more inclined to question AI-generated responses, while reflective interaction with these systems may also provide opportunities to practise such behaviours. The cross-sectional design does not permit these alternative explanations to be distinguished. Moreover, both constructs were measured through self-report, creating the possibility that their association partly reflects shared response tendencies or conceptual overlap between questionnaire items.

The negative relationship between passive reliance and critical thinking introduces an additional consideration. Students who reported greater dependence on ready-made AI-generated answers tended to report weaker evaluative practices. This finding is consistent with the concerns discussed by Sardi et al. (2025), whose systematic review identifies the potential limitations of excessive dependence on automated assistance for self-regulated learning. Comparable concerns appear in Fischer et al. (2024), who demonstrate the importance of distinguishing AI-supported academic production from the independent cognitive work expected in higher education. The present findings suggest that reflective and passive approaches should not be treated as interchangeable indicators of generative AI adoption. Both involve technological engagement, but they differ in the degree of responsibility students retain for evaluating evidence and constructing conclusions. At the same time, the modest negative correlation between the two scales indicates that they are not simply opposite ends of a single continuum. Students may use generative AI reflectively in some academic situations while relying on automatically generated responses in others. The second hypothesis concerned the relationship between pedagogical guidance and reflective GenAI use. The positive association observed in the correlation and regression analyses suggests that students who perceived stronger instructional expectations concerning verification, justification, and critical examination of AI-generated information were more likely to report reflective engagement. This result is consistent with the pedagogical perspective presented by King and Lopour (2025), whose instructional approach emphasizes the deliberate examination of AI-generated content rather than its uncritical acceptance.

The findings also complement the arguments advanced by Choi et al. (2024) concerning the importance of professional judgment when generative AI is incorporated into educational activities. Although automated systems can facilitate content production and instructional preparation, their educational appropriateness depends on the ability of users to evaluate the relevance, accuracy, and limitations of generated materials. For pre-service teachers, this requirement extends beyond immediate academic tasks because the practices developed during university education may inform their subsequent professional decisions. An important distinction concerns the measurement of pedagogical guidance. The present study assessed students' perceptions of instructors' practices rather than directly observing teaching strategies or evaluating the implementation of a structured instructional intervention. Consequently, the findings indicate an association between perceived pedagogical guidance and reflective AI use, but they do not establish that particular teaching strategies caused students to adopt reflective behaviours. Longitudinal and intervention-based research would be required to examine this

possibility. The role of digital competence provides further insight into the relationships under investigation. Its positive associations with reflective GenAI use and critical thinking suggest that students' perceived ability to formulate prompts, identify technological limitations, and verify generated information is relevant to their broader evaluative practices. This finding corresponds to the conceptualization of AI literacy developed by Ng et al. (2021), which integrates technological understanding, application, evaluation, and ethical considerations. However, the present digital competence measure was based on self-assessment and should not be interpreted as an independently validated test of AI literacy. The absence of a statistically significant association between frequency of GenAI use and critical thinking in the adjusted model is also noteworthy. It suggests that differences in the amount of reported AI use were not independently associated with the outcome once reflective engagement, passive reliance, digital competence, and demographic characteristics were considered. This result reinforces the argument that technological adoption and educationally productive engagement should be examined as analytically distinct dimensions. Taken together, the findings support an interpretation of generative AI as a learning resource whose educational significance depends partly on how students engage with its outputs and how instructors communicate expectations concerning their use. The results do not justify a simple distinction between beneficial and harmful AI use. Rather, they suggest that the relationship between generative AI and critical thinking is differentiated by the cognitive and instructional practices accompanying technological engagement. For teacher education programmes, the findings point towards the potential relevance of activities that require students to compare AI-generated explanations with scholarly evidence, identify unsupported claims, justify their interpretations, and reflect on the limitations of automated responses. Such activities may provide opportunities to integrate AI literacy with existing expectations concerning independent academic reasoning. Their effectiveness, however, remains a question for subsequent experimental or longitudinal investigation.

The interpretation of these findings is subject to several limitations. The sample was restricted to five higher education institutions, and the observed demographic composition limits generalization to the wider population of pre-service teachers in Kazakhstan. The use of cross-sectional self-reported measures introduces possible common-method variance and does not permit causal inference. Furthermore, the critical thinking measure assessed perceived analytical practices rather than objectively demonstrated performance. Future studies could address these limitations by combining validated performance-based assessments, classroom observations, longitudinal measurement, and experimentally evaluated pedagogical interventions.

Conclusion

This study examined the relationships between reflective generative artificial intelligence use, perceived pedagogical guidance, and self-reported critical thinking competencies among 293 pre-service teachers from five higher education institutions in Kazakhstan. By distinguishing reflective engagement from passive reliance on AI-generated responses, the research sought to clarify how different patterns of technological use are associated with students' evaluative learning practices. The findings suggest that the educational significance of generative AI cannot be adequately understood through the frequency of its use alone. Greater analytical attention is required to the cognitive activities students undertake when interpreting, verifying, and applying automatically generated information. The results provided statistical support for both research hypotheses. Reflective GenAI use demonstrated a moderate positive association with self-reported critical thinking ($\rho = 0.542$, $p < .001$), indicating that students who more frequently reported verifying information, comparing alternative explanations, and critically examining AI-generated responses also tended to report stronger analytical and evaluative practices. This relationship remained statistically significant after adjustment for passive reliance, digital

competence, frequency of GenAI use, age, and year of study (B = 0.436, p < .001). The findings are consistent with the theoretical assumption that reflective engagement with generative technologies is associated with the intellectual practices underlying critical thinking. Nevertheless, the observed relationship should not be interpreted as evidence that AI use independently improves cognitive competence. The second hypothesis was also supported. Perceived pedagogical guidance was positively associated with reflective GenAI use (ρ = 0.427, p < .001), and the relationship remained significant in the adjusted regression model (B = 0.381, p < .001). Students who reported greater instructional emphasis on evaluating AI-generated information, verifying sources, and justifying academic conclusions were more likely to describe their own AI use as reflective. This finding suggests that instructional expectations are relevant to understanding differences in students' engagement with generative technologies. However, because pedagogical guidance was measured through students' perceptions, the results cannot establish the effectiveness of particular teaching strategies or determine whether instructional practices directly produced changes in learning behaviour.

An additional finding concerns the distinction between reflective engagement and passive reliance. Passive reliance was negatively associated with self-reported critical thinking (ρ = −0.311, p < .001) and remained a significant negative predictor in the adjusted regression model. Digital competence, by contrast, demonstrated positive associations with both reflective AI use and critical thinking. These relationships indicate that students' engagement with generative AI involves several analytically distinct dimensions. Technological familiarity, independent evaluation, and dependence on automated responses should not be treated as interchangeable indicators of educational technology use. The absence of a statistically significant independent association between GenAI-use frequency and critical thinking in the adjusted model further supports this distinction. The theoretical contribution of the study lies in connecting constructivist approaches to learning, self-regulated learning, and AI literacy within an empirical framework focused on pre-service teacher education. The findings are consistent with the proposition that students' reported critical thinking is associated not simply with access to generative technologies but with the ways in which they evaluate and incorporate AI-generated information into their academic reasoning. The relationship between pedagogical guidance and reflective engagement also extends this perspective by drawing attention to the instructional context in which individual learning practices develop. Within the context of Kazakhstan's higher education system, the study provides evidence relevant to understanding how future teachers perceive and use generative AI during their professional preparation. From a practical perspective, the findings suggest that teacher education programmes should consider integrating structured activities requiring students to examine the accuracy of AI-generated explanations, compare automated responses with scholarly sources, identify unsupported arguments, and justify their academic decisions. Such activities could be incorporated into coursework, independent assignments, and instructional discussions concerning responsible AI use. The objective would not be to discourage engagement with generative technologies but to maintain students' responsibility for evaluating evidence and constructing reasoned conclusions. The effectiveness of these approaches, however, requires direct assessment rather than inference from the associations observed in the present study.

Several limitations should be acknowledged. The cross-sectional design prevents conclusions about causal relationships or changes in critical thinking over time. The reliance on self-reported measures introduces potential common-method bias and limits the interpretation of critical thinking as an independently demonstrated cognitive competence. Furthermore, the institutional and demographic composition of the sample restricts the generalizability of the findings to the broader population of pre-service teachers in Kazakhstan. Future research should employ longitudinal and experimental designs, incorporate performance-based measures of critical thinking, and examine how specific instructional strategies influence students' ability to

evaluate AI-generated information across different educational contexts. The study indicates that reflective engagement with generative AI and perceived pedagogical guidance are positively associated with the critical and evaluative learning practices reported by pre-service teachers. Its principal implication is that the educational integration of generative AI should be considered not only in terms of technological accessibility or frequency of use but also in relation to the intellectual responsibilities retained by students and the instructional expectations established by educators. For teacher education, this distinction provides a basis for developing pedagogical approaches that combine the practical possibilities of generative AI with the continued cultivation of independent academic judgment.

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БИОЛОГИЯНЫ AR/VR ТЕХНОЛОГИЯЛАРЫ АРҚЫЛЫ ОҚЫТУ ӘДІСТЕМЕСІНІҢ ТИІМДІЛІГІН ЗЕРТТЕУ

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Аннотация.

Биология пәнінің көптеген тақырыптары көзге көрінбейтін құрылымдар мен динамикалық процестерді сипаттайтындықтан, оларды дәстүрлі көрнекі құралдар арқылы түсіндіру оңай емес. Осы мәселені шешу мақсатында біз 8-сынып биологиясын толықтырылған және виртуалды шындық (AR/VR) технологиялары арқылы оқыту әдістемесін әзірлеп, оның оқушылардың пәндік жетістігіне әсерін эксперимент жүзінде тексердік. Зерттеу бақылау тобы бар квазиэкспериментттік дизайн бойынша жүргізіліп, оған 60 оқушы қатысты. Эксперименттік топ (n = 30) сегіз апта бойы 5E моделіне негізделген AR/VR әдістемесі бойынша оқыса, бақылау тобы (n = 30) сол тақырыптарды дәстүрлі әдіспен меңгерді. Алдын ала тестілеуде топтардың деңгейі бірдей болып шықты (p = 0,201), ал бастапқы деңгейді ескеретін ковариациялық талдау (ANCOVA) эксперименттің соңында эксперименттік топтың нәтижесі мәнді түрде жоғары екенін көрсетті (түзетілген орташалар 70,5 және 66,2 балл; F(1, 57) = 4,70; p = 0,034; $\eta^2 p$ = 0,076). Оқушылардың білім өсімі эксперименттік топта орта есеппен 9,8 баллды, бақылау тобында 5,5 баллды құрады (Hedges g = 0,58), ал жоғары деңгейге жеткен оқушылар үлесі 10 %-дан 43 %-ға дейін артты. Бұл нәтижелер иммерсивті технологиялар сабақтың әдістемелік құрылымына жүйелі түрде енгізілгенде биологиялық білімді меңгеру тиімділігі артатынын көрсетеді.

Түйін сөздер: толықтырылған шындық, виртуалды шындық, биологияны оқыту әдістемесі, иммерсивті оқыту, пәндік жетістік, квазиэксперимент.

1. Кіріспе

Жаратылыстану пәндерін оқытуда мұғалімдер жиі кездесетін қиындықтардың бірі — оқушыларға тікелей бақылауға келмейтін объектілер мен процестер туралы тұтас түсінік қалыптастыру. Биологияда бұл мәселе ерекше байқалады, себебі пән мазмұнының едәуір бөлігін жасуша құрылымы, қан айналымы, тыныс алу мен жүйке реттелуі сияқты кеңістікте өтетін және уақыт бойынша өзгеретін құбылыстар құрайды. Оқулықтағы екі өлшемді суреттер мен статикалық муляждар бұл құбылыстардың құрылымы мен динамикасын толық жеткізе алмайды, нәтижесінде оқушыларда тұжырымдамалық қателіктер қалыптасып жатады.

Осындай олқылықтың орнын толтыруға иммерсивті технологиялар жаңа мүмкіндік береді. Толықтырылған шындық (AR) нақты ортаның үстіне цифрлық үш өлшемді объектілерді қабаттастырады, ал виртуалды шындық (VR) пайдаланушыны толықтай жасанды ортаға енгізеді (Azuma, 1997; Milgram & Kishino, 1994). Екі технологияның да ортақ артықшылығы — оқушы кеңістіктік модельдермен тікелей әрекеттесіп, оларды әр қырынан қарастыра алады және әдетте жасырын жүретін процестерді өз көзімен көреді. Қазақстанда

білім беруді цифрландыру аясында мектептердің техникалық жабдықталуы жақсарып келеді, алайда бұл құралдарды биология сабағына қалай тиімді енгізу керектігі отандық ғылыми әдебиетте әлі жеткілікті зерттелмеген.

Халықаралық тәжірибеге жүгінсек, метаталдаулар иммерсивті технологиялардың оқу нәтижелеріне оң әсер ететінін растайды, бірақ бұл әсердің шамасы технология түріне және оны қолдану жағдайына қарай айтарлықтай өзгеріп отырады. Мәселен, Cromley және т.б. (2023) STEM пәндері бойынша VR-дың жалпы әсерін g = 0,33 деп бағалап, ең жоғары нәтиже белсенді оқыту тәсілдері қолданылған зерттеулерде байқалатынын атап өтті. Coban және т.б. (2022) иммерсивті VR үшін осыған жақын нәтиже алды (g = 0,38). Толықтырылған шындыққа келгенде көрсеткіштер әлдеқайда жоғары: жаратылыстану пәндері мен биология бойынша 15 зерттеуді талдаған Faria мен Miranda (2024) оқу нәтижелері үшін d = 1,13 мәнін анықтаса, Barcenas пен Prudente (2026) орта мектеп оқушылары бойынша g = 0,98 жалпы әсерді тіркеді. Соңғы авторлар AR-ды 6–8 апта бойы қолданудың 1–3 апталық қолданудан әлдеқайда тиімді екенін де көрсетті (g = 1,63 және g = 0,72). Мектеп биологиясына қатысты зерттеулер де осы үрдісті растайды: жасушаның бөлінуін оқытуда VR, интерактивті тақта және дәстүрлі әдісті салыстырғанда иммерсия деңгейі жоғары топтың нәтижесі ең жоғары болған (Neiroukh және т.б., 2025).

Дегенмен иммерсияның өзі оқу нәтижесін автоматты түрде жақсарта бермейді. Makransky және т.б. (2019) иммерсия деңгейі жоғарылаған сайын оқушының қатысу сезімі күшейгенімен, когнитивтік жүктеме де артып, соның салдарынан білім меңгеру төмендеуі мүмкін екенін анықтады. Демек технологияның тиімділігі оның сабақтың қай кезеңінде және қандай мақсатпен қолданылатынына тікелей байланысты. Біз ұсынып отырған әдістеме де осы тұжырымға сүйенеді: оның теориялық негізін мультимедиалық оқытудың когнитивтік теориясы (Mayer, 2014), когнитивтік жүктеме теориясы (Sweller және т.б., 2011) және иммерсивті оқытудың когнитивті-аффектілік моделі (CAMIL; Makransky & Petersen, 2021) құрайды. Аталған тұжырымдамаларға сәйкес AR/VR құралдары сабақтың белгілі бір кезеңінде ғана қолданылып, алынған әсер мұғалімнің түсіндіруі мен оқушылардың рефлексиясы арқылы бекітілуі қажет.

Әдебиетке жасалған шолу тағы бір маңызды олқылықты көрсетеді. Зерттеулердің басым бөлігі жоғары оқу орындарында немесе бірнеше сабақпен шектелетін қысқа мерзімді интервенция түрінде жүргізілген. AR мен VR технологияларын бір әдістемелік жүйеге біріктіріп, оны мектеп бағдарламасы аясында бірнеше апта бойы сынақтан өткізген жұмыстар санаулы, ал қазақ тілінде оқитын мектеп оқушылары бойынша мұндай эксперименттік деректер іс жүзінде жоқ. Зерттеудің өзектілігі де осы жағдаймен айқындалады.

Осыған байланысты зерттеудің мақсаты ретінде 8-сынып биологиясын оқытуға арналған AR/VR негізіндегі әдістемені әзірлеп, оның оқушылардың пәндік жетістігіне әсерін эксперимент арқылы бағалау белгіленді. Осы мақсатқа жету үшін біз екі сұраққа жауап іздедік. Біріншіден, бастапқы деңгейді ескергенде AR/VR әдістемесі бойынша оқыған оқушылардың қорытынды нәтижесі дәстүрлі әдіспен оқыған құрдастарының нәтижесінен ерекшелене ме? Екіншіден, екі топта білім өсімінің шамасы және оқушылардың жетістік деңгейлері бойынша таралуы қалай өзгереді? Біздің болжамымыз бойынша, эксперименттік топтың қорытынды нәтижесі мен білім өсімі бақылау тобынан жоғары болады (H1), ал жоғары деңгейге жеткен оқушылардың үлесі бұл топта көбірек артады (H2).

2. Материалдар мен әдістер

2.1. Зерттеу дизайны және қатысушылар

Зерттеу бақылау тобы бар, алдын ала және қорытынды тестілеуді қамтитын квазиэкспериментік дизайн бойынша ұйымдастырылды. Мектептің оқу кестесі оқушыларды топтарға жекелей бөлуге мүмкіндік бермегендіктен, сыныптар бүтіндей алынып, жеребе арқылы эксперименттік және бақылау топтарына бөлінді. Тәуелсіз айнымалы ретінде оқыту әдісі, ал тәуелді айнымалы ретінде оқушылардың пәндік тесттен жинаған баллы алынды.

Эксперимент Алматы қаласындағы Ш. К. Беркімбаева атындағы қыздар мектеп-лицей-интернаты базасында өтті. Оған қазақ тілінде білім алатын 8-сыныптың 60 оқушы қызы қатысып, олар тең екіге бөлінді: 30 оқушы эксперименттік топқа (ЭТ), 30 оқушы бақылау тобына (БТ) енді. Барлық қатысушылар екі тестілеуден де өткендіктен, талдау толық таңдама бойынша жүргізілді. Нәтижеге мұғалімнің жеке шеберлігі әсер етпеуі үшін екі топтағы сабақтарды бір мұғалім жүргізді. Таңдама көлемін G*Power 3.1 бағдарламасымен алдын ала есептегенде (Faul және т.б., 2009) ковариациялық талдауда орташа әсерді ($f = 0,25$; $\alpha = 0,05$; $1 - \beta = 0,80$) анықтау үшін кемінде 128 қатысушы қажет екені анықталды. Сондықтан бұл зерттеуді пилоттық жұмыс ретінде қарастырған жөн.

2.2. Оқыту әдістемесі

Эксперименттік оқыту сегіз аптаға созылды: аптасына екі сабақ, барлығы 16 сабақ, әрқайсысы 40 минуттан. Оқу мазмұны 8-сыныпқа арналған биологияның үлгілік оқу бағдарламасынан алынып, қан және қан айналымы, тыныс алу және жүйке жүйесі тақырыптарын қамтыды. Әр сабақ 5E оқыту моделінің (Bybee және т.б., 2006) кезеңдеріне сәйкес құрылды. Сабақ басында мұғалім проблемалық сұрақ қойып, оқушылардың қызығушылығын оятты (5 минут). Одан кейінгі зерттеу кезеңінде (12 минут) оқушылар жұптасып, планшеттегі AR қосымшасы арқылы мүшелер мен жасушалардың үш өлшемді модельдерін зерделеді, ал VR гарнитурасы арқылы қанның тамырлар бойымен айналуы немесе жүйке импульсінің таралуы сияқты процестерді бақылады. Жасөспірімдердің қауіпсіздігін ескеріп, бір VR сеансы 10 минуттан аспады, ал гарнитуралар станциялар бойынша кезекпен пайдаланылды. Зерттеуден кейін мұғалім оқушылардың бақылауларын ғылыми ұғымдармен байланыстырып түсіндірді (8 минут), ал оқушылар жұптық тапсырма орындау арқылы алған білімдерін тереңдетті (10 минут). Сабақ қысқа қалыптастырушы бағалау мен рефлексиямен аяқталды (5 минут). AR/VR құралдарының тек зерттеу кезеңімен шектелуі кіріспеде аталған қауіпті, яғни технологиялық ортаның артық когнитивтік жүктеме тудыруын болдырмауға бағытталды.

Бақылау тобы дәл сол тақырыптарды бірдей құрылымдағы сабақтарда меңгерді, айырмашылығы тек зерттеу кезеңінде болды: осы жерде оқушылар AR/VR орнына оқулықты, плакаттар мен муляждарды пайдаланды. Осылайша топтар арасындағы айырмашылықты сабақ құрылымына емес, тікелей көрнекілік құралдарының түріне жатқызуға мүмкіндік туды (Clark, 1994).

2.3. Өлшеу құралы және зерттеу рәсімі

Оқушылардың пәндік жетістігін өлшеу үшін авторлар оқу бағдарламасының тиісті бөлімдерін қамтитын тест әзірледі, оның нәтижесі 0–100 баллдық шкалаға келтірілді. Талдауды жеңілдету үшін оқушылар жинаған баллына қарай үш деңгейге бөлінді: төмен (0–49 балл), орта (50–74 балл) және жоғары (75–100 балл). Тесттің мазмұндық валидтілігін пән мұғалімдері сараптады.

Тест екі рет өткізілді: алдын ала тест эксперимент басталар алдында, қорытынды тест сегіз апталық оқытудан кейін. Алдын ала тесттен кейін эксперименттік топтың оқушылары AR/VR құралдарымен алдын ала танысты, бұл техникалық қиындықтардың негізгі сабақтарға әсер етпеуін қамтамасыз етті. Эксперимент барысында сабақтардың бір бөлігіне тәуелсіз сарапшы қатысып, олардың жоспарға сәйкес өтуін бақылау парағы бойынша бағалады. Тест

жұмыстарын оқушының қай топта екенін білмейтін тексеруші бағалады, бұл бағалаудағы бейтараптықты қамтамасыз етті.

2.4. Деректерді статистикалық өңдеу

Деректер Python ортасында SciPy және statsmodels кітапханаларының көмегімен өңделді, мәнділік деңгейі α = 0,05 деп алынды. Талдауды бастамас бұрын біз таңдалған әдістердің алғышарттарын тексердік: өсім көрсеткіштерінің қалыпты таралуы Shapiro–Wilk критерийімен, дисперсиялардың біртектілігі Levene критерийімен, ал регрессия көлбеулерінің біртектілігі топ пен алдын ала тесттің өзара әрекеттесуі арқылы бағаланды. Топтардың бастапқы деңгейі Welch t-критерийі бойынша салыстырылды.

Бірінші болжамды (H1) тексерудің негізгі әдісі ретінде ковариациялық талдау (ANCOVA) таңдалды: модельге алдын ала тест баллы ковариат ретінде енгізіліп, әсер шамасы ішінар детерминация коэффициентімен (η^2p) бағаланды. Нәтиженің сенімділігін арттыру үшін топтардың өсімдері қосымша түрде екі тәсілмен — Welch t-критерийі және параметрлік емес Mann–Whitney U критерийі арқылы — салыстырылды, ал әсер шамасы Hedges g коэффициенті мен 95 %-дық сенім аралығы арқылы сипатталды. Әр топтың ішіндегі өзгеріс жұптасқан t-критерийімен тексерілді, сондай-ақ бастапқы деңгейдің әсерін ескеру үшін Hake (1998) ұсынған нормаланған артықшылық көрсеткіші есептелді. Екінші болжамды (H2) тексеру үшін оқушылардың жетістік деңгейлері бойынша таралуы эксперименттің басы мен соңында салыстырылды.

2.5. Зерттеудің этикалық аспектілері

Эксперимент мектеп әкімшілігінің рұқсатымен жүргізіліп, оған дейін ата-аналардан жазбаша келісім, оқушылардан ерікті келісім алынды. Жиналған деректер анонимденді. VR сеанстары мұғалімнің үнемі қадағалауымен өтті және оқушыда бас айналу немесе жүрек айну сияқты киберауру белгілері байқалса, сеанс дереу тоқтатылды. Эксперимент аяқталғаннан кейін бақылау тобындағы оқушылар да AR/VR сабақтарына қатыса алды.

3. Нәтижелер

3.1. Топтардың бастапқы сипаттамасы

Алдын ала тестілеу нәтижесі бойынша эксперименттік топтың орташа баллы 62,33 (SD = 10,06), бақылау тобының орташа баллы 59,10 (SD = 9,30) болды. Топтар арасындағы 3,23 баллдық айырма статистикалық тұрғыдан мәнді емес ($t(57,6) = 1,29$; $p = 0,201$), бұл топтардың бастапқы дайындығы салыстырмалы тұрғыда бірдей екенін көрсетеді. Соған қарамастан бастапқы деңгейдегі аздаған айырманың әсерін бейтараптау мақсатында негізгі талдау ковариациялық модель арқылы жүргізілді.

Ковариациялық талдаудың алғышарттары орындалды. Өсім көрсеткіштерінің таралуы екі топта да қалыпты таралудан мәнді ауытқан жоқ (Shapiro–Wilk: ЭТ үшін $W = 0,978$, $p = 0,777$; БТ үшін $W = 0,941$, $p = 0,099$), дисперсиялар біртекті (Levene $F = 0,18$; $p = 0,673$), ал топ пен алдын ала тест арасындағы өзара әрекеттесудің мәнді болмауы ($p = 0,775$) регрессия көлбеулерінің біртектілігін растайды.

3.2. Пәндік жетістікке әсер

Алдын ала тест баллын бақылау арқылы жүргізілген ковариациялық талдау оқыту әдісінің қорытынды жетістікке статистикалық тұрғыдан мәнді әсерін анықтады: $F(1, 57) = 4,70$; $p = 0,034$; $\eta^2p = 0,076$. Түзетілген орташа мәндер эксперименттік топта 70,5 баллды, бақылау тобында 66,2 баллды құрады. Алдын ала тест баллы қорытынды нәтиженің күшті болжамдауышысы болды ($F(1, 57) = 100,09$; $p < 0,001$), бұл ковариатты енгізудің негізділігін көрсетеді. Топтардың негізгі көрсеткіштері 1-кестеде берілген.

1-кесте. Пәндік тест нәтижелерінің сипаттамалық және инференциялық статистикасы (0–100 балл; әр топта n = 30)

Көрсеткіш	ЭТ	БТ	Айырма	Статистикалық критерий
Алдын ала тест, M (SD)	62,33 (10,06)	59,10 (9,30)	3,23	t(57,6) = 1,29; p = 0,201
Қорытынды тест, M (SD)	72,17 (12,84)	64,57 (12,01)	7,60	t(57,7) = 2,37; p = 0,021
Қорытынды тест, түзетілген M	70,5	66,2	4,3	F(1, 57) = 4,70; p = 0,034; η^2p = 0,076
Өсім, M (SD)	9,83 (7,30)	5,47 (7,68)	4,37 [0,49; 8,24]	t(57,8) = 2,26; p = 0,028; g = 0,58
Өсім, бастапқы деңгейден %	15,8	9,2	6,5	—
Нормаланған артықшылық ⟨g⟩	0,26	0,13	0,13	—

Ескерту: ЭТ — эксперименттік топ, БТ — бақылау тобы; t — Welch критерийі; түзетілген орташалар алдын ала тесттің жалпы орташасы (60,72) бойынша есептелді; тік жақшада — айырманың 95 %-дық сенім аралығы.

Өсім көрсеткіштерін салыстыру да ұқсас нәтиже берді: эксперименттік топтағы орташа өсім бақылау тобынан 4,37 баллға жоғары болды, бұл орташа шамадағы әсерге сәйкес келеді (Hedges g = 0,58). Алынған нәтиже параметрлік емес Mann–Whitney U критерийі бойынша да расталды (U = 601; p = 0,026). Нормаланған артықшылық көрсеткішінің эксперименттік топта екі есе жоғары болуы (0,26 және 0,13) оқушылардың бастапқы деңгейіндегі айырмашылықты ескергенде де артықшылықтың сақталатынын көрсетеді. Осылайша, бірінші болжам (H1) расталды.

3.3. Топ ішіндегі өзгерістер және жетістік деңгейлері

Екі топта да зерттеу кезеңінде статистикалық тұрғыдан мәнді оң өзгерістер байқалды, алайда олардың айқындығы ерекшеленді: эксперименттік топта t(29) = 7,38 (p < 0,001), бақылау тобында t(29) = 3,90 (p < 0,001). Эксперименттік топта нәтижесі төмендеген оқушылар саны үшеу болса, бақылау тобында сегіз болды.

Оқушылардың жетістік деңгейлері бойынша таралуы 2-кестеде келтірілген. Эксперименттік топта жоғары деңгейдегі оқушылар үлесі 10 %-дан 43,3 %-ға дейін артып, төмен деңгейдегі оқушылар толықтай орта немесе жоғары деңгейге ауысты. Бақылау тобында жоғары деңгейдің үлесі 3,3 %-дан 20 %-ға дейін өсті, ал екі оқушы төмен деңгейде қалды. Алынған деректер екінші болжамды (H2) растайды.

2-кесте. Оқушылардың жетістік деңгейлері бойынша таралуы, оқушы саны (%)

Топ және өлшеу кезеңі	Төмен (0–49)	Орта (50–74)	Жоғары (75–100)
ЭТ, алдын ала тест	4 (13,3)	23 (76,7)	3 (10,0)
ЭТ, қорытынды тест	0 (0,0)	17 (56,7)	13 (43,3)
БТ, алдын ала тест	3 (10,0)	26 (86,7)	1 (3,3)
БТ, қорытынды тест	2 (6,7)	22 (73,3)	6 (20,0)

4. Талқылау

Зерттеу нәтижелері биологияны оқытуда толықтырылған және виртуалды шындық технологияларын жүйелі түрде қолдану 8-сынып оқушыларының пәндік жетістігіне оң әсер ететінін көрсетті. Бастапқы деңгей ескерілген жағдайда эксперименттік топтың қорытынды нәтижесі бақылау тобынан 4,3 баллға жоғары болды, ал өсімдер бойынша есептелген әсер

шамасы (g = 0,58) орташа деңгейге сәйкес келеді. Алынған мән VR бойынша жүргізілген метаталдауларда анықталған көрсеткіштерден (g = 0,33–0,38; Cromley және т.б., 2023; Coban және т.б., 2022) жоғары, ал биология мен жаратылыстану пәндеріндегі AR бойынша жинақталған деректерден (d = 1,13; g = 0,98; Faria & Miranda, 2024; Barcenas & Prudente, 2026) төмен. Әсер шамасының аталған аралықта орналасуы ұсынылған әдістемеде екі технологияның біріктіріліп қолданылуымен түсіндірілуі мүмкін.

Нәтижелерді түсіндіруде бақылау тобындағы мәнді өсімді де назардан тыс қалдырмау қажет. Екі топтағы сабақтар 5E моделіне сәйкес бірдей құрылымда өткізілгендіктен, белсенді оқытудың өзі білім деңгейінің артуына ықпал еткені айқын. Сондықтан топтар арасындағы айырмашылықты иммерсивті көрнекіліктің қосымша үлесі ретінде бағалауға негіз бар. Бұл тұжырым технологияның тиімділігі одан гөрі оның әдістемелік қалай пайдаланылатынына тәуелді деген көзқараспен (Clark, 1994; Makransky & Petersen, 2021) үйлеседі.

Жетістік деңгейлері бойынша талдау әдістеменің әсері тек орташа көрсеткіштермен шектелмейтінін көрсетті. Эксперименттік топта төмен деңгейдегі оқушылардың бәрі жоғары деңгейлерге ауысып, жоғары деңгейдегі оқушылар үлесі төрт еседен астам артты, ал нәтижесі төмендеген оқушылар саны бақылау тобына қарағанда айтарлықтай аз болды. Бұл үш өлшемді визуализацияның кеңістіктік бейнелеуде қиындық көретін оқушыларға ерекше қолдау көрсететінін білдіруі мүмкін, алайда бұл болжам арнайы тексеруді талап етеді. Сондай-ақ сегіз апталық интервенция нәтижелері Barcenas пен Prudente (2026) анықтаған заңдылыққа, яғни иммерсивті технологияларды ұзақ мерзім қолданудың тиімділігі жоғары болатынына қайшы келмейді.

Сонымен қатар, алынған нәтижелер сақтықпен түсіндірілуі тиіс. Таңдама көлемінің шағындығына байланысты өсім айырмашылығының сенім аралығы кең (0,49–8,24 балл), ал квазиэксперименттік дизайн және бір мектеп базасында жүргізілген зерттеу нәтижелерді жалпылау мүмкіндігін шектейді. Сондай-ақ таңдама тек қыздардан құралғандықтан, алынған нәтижелерді аралас сыныптарға қолдану қосымша тексеруді талап етеді.

5. Қорытынды

Зерттеу барысында 8-сынып биологиясын оқытуға арналған, 5E моделіне негізделген AR/VR әдістемесі әзірленіп, оның тиімділігі квазиэксперимент арқылы тексерілді. Эксперимент нәтижелері ұсынылған әдістеме бойынша білім алған оқушылардың қорытынды жетістігі мен білім өсімі дәстүрлі әдіспен оқыған оқушылардың көрсеткіштерінен статистикалық тұрғыдан мәнді түрде жоғары екенін көрсетті ($F(1, 57) = 4,70$; $p = 0,034$; $g = 0,58$). Алынған деректер иммерсивті технологиялардың тиімділігі олардың сабақтың әдістемелік құрылымына мақсатты түрде енгізілуіне тәуелді екенін растайды. Ұсынылған әдістеме мен сабақ үлгісін жалпы білім беретін мектептердің биология мұғалімдері оқу процесінде қолдана алады.

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Philological Sciences

Teaching Ways of Stylistic Terms: Samples from Literature and Colloquial Speech

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Abstract

The teaching of stylistic terms is an essential component of linguistic and literary education because it enables students to understand how language functions in different communicative contexts. Stylistic devices such as metaphor, simile, personification, irony, hyperbole, euphemism, metonymy, and repetition contribute to the expressive, emotional, and aesthetic dimensions of language. However, students frequently encounter difficulties distinguishing these terms, identifying their functions, and applying theoretical knowledge to authentic language examples. This article examines effective approaches to teaching stylistic terminology through examples drawn from literary texts and colloquial speech. It explores the relationship between theoretical explanation, contextual analysis, comparative learning, and practical exercises. Particular attention is paid to demonstrating how the same stylistic device may function differently in literary and everyday communication. The study employs descriptive, comparative, contextual, and analytical methods to investigate the pedagogical value of authentic examples. The findings suggest that integrating literary language with colloquial expressions enhances students' understanding of stylistic concepts, develops linguistic awareness, and improves their ability to interpret expressive meaning. The article argues that contextualized and example-based instruction provides an effective framework for teaching stylistics and developing students' communicative and analytical competence.

Keywords: stylistics, stylistic terms, literary language, colloquial speech, language teaching, stylistic devices, figurative language, contextual analysis.

1. Introduction

Stylistics occupies an important position in the study of language because it investigates the ways in which linguistic resources are selected and organized to achieve particular communicative, expressive, and aesthetic effects. Unlike approaches that concentrate exclusively on grammatical structures or lexical meanings, stylistics examines how language choices contribute to the creation of meaning in different situations. It considers the relationship between linguistic form, communicative intention, context, and the individual characteristics of speakers and writers.

The teaching of stylistics is particularly important in higher education, where students are expected not only to recognize linguistic phenomena but also to explain their functions and interpret their effects. Knowledge of stylistic terminology enables learners to understand literary texts more deeply, recognize expressive features in everyday communication, and develop their own writing and speaking skills.

One of the main challenges in teaching stylistic terms is the abstract nature of many concepts. Students may memorize definitions of metaphor, metonymy, irony, hyperbole, personification, and other stylistic devices without fully understanding how these phenomena operate in actual communication. For instance, a learner may know that metaphor involves transferring meaning on the basis of similarity but may have difficulty identifying the metaphorical

function of an expression such as a storm of emotions. Similarly, students may understand the definition of irony but fail to recognize it when it appears in an ordinary conversation.

According to Leech and Short (2007), stylistic analysis involves examining linguistic choices and their contribution to the interpretation of literary texts. Such an approach demonstrates that stylistic terminology should not be taught as an isolated collection of definitions [3]. Instead, theoretical explanations should be accompanied by contextual examples that demonstrate how particular linguistic structures produce meaning.

Wales (2011) also emphasizes the importance of understanding stylistic concepts in relation to actual language use. Stylistic analysis is concerned with the expressive potential of linguistic forms and the ways in which they function in different contexts [4].

Literary language provides a particularly rich source of examples for teaching stylistic terminology. Novels, short stories, poetry, and dramatic works contain numerous instances of figurative language, sound patterns, repetition, and syntactic variation [12]. Authors deliberately employ these resources to construct characters, establish atmosphere, communicate emotions, and influence readers.

At the same time, colloquial speech offers valuable opportunities for demonstrating that stylistic devices are not restricted to literature [1]. Everyday communication frequently includes metaphors, exaggerations, comparisons, euphemisms, rhetorical questions, and ironic expressions. Phrases such as I'm drowning in work, He's as stubborn as a mule, and That's just wonderful! may illustrate stylistic processes in ordinary communication, depending on their context.

The comparison of literary and colloquial examples is therefore particularly effective because it allows students to recognize the relationship between language and communicative purpose. A metaphor in a literary text may create an aesthetic image, whereas a metaphor in everyday speech may make an explanation more vivid or emotionally expressive.

The present study aims to investigate effective methods of teaching stylistic terms through examples taken from literature and colloquial speech [6]. It focuses on the following research questions:

1. How can literary and colloquial examples facilitate the understanding of stylistic terminology?
2. What teaching techniques are most appropriate for explaining major stylistic devices?
3. How does the comparison of literary and everyday expressions develop students' ability to identify stylistic functions?
4. How can practical exercises improve students' application of stylistic terminology in communication and textual analysis?

The central argument of the study is that stylistic terminology is most effectively taught through a combination of theoretical explanation, contextual interpretation, comparative analysis, and practical application.

2. Methods

The research is based on a qualitative, descriptive-analytical approach to the teaching of stylistic terminology. It combines linguistic analysis with pedagogical interpretation to identify effective ways of presenting stylistic concepts to students.

Four principal research methods are employed.

2.1. Descriptive method

The descriptive method is used to explain the definitions, linguistic characteristics, and communicative functions of major stylistic devices. The study considers the following categories:

- Lexical stylistic devices: metaphor, simile, personification, metonymy, hyperbole, irony, and euphemism.

- Syntactical stylistic devices: repetition, parallelism, rhetorical questions, inversion, and ellipsis.
- Phonetic stylistic devices: alliteration, assonance, onomatopoeia, and rhythm.
- Semantic stylistic devices: ambiguity, contrast, paradox, and oxymoron.

2.2. Comparative method

The comparative method is employed to examine how the same stylistic device appears in literary texts and colloquial communication. This approach makes it possible to demonstrate similarities and differences in the functions of stylistic expressions across different registers.

2.3. Contextual method

The contextual method examines stylistic expressions within their surrounding linguistic and communicative environments. Particular attention is given to the speaker's intention, emotional condition, relationship with the listener, and the overall situation.

2.4. Analytical method

The analytical method is used to investigate the expressive and educational functions of stylistic devices [9]. Examples are examined to determine how they contribute to meaning, emotional impact, characterization, and communicative effectiveness.

The illustrative material consists of selected examples from well-known literary works and constructed examples representing ordinary conversational situations. The examples are used to demonstrate teaching procedures rather than to establish statistical frequencies. Consequently, the findings are qualitative and pedagogical rather than experimental.

3. Results

The analysis identifies several teaching approaches that can facilitate the acquisition of stylistic terminology. The most effective approach is to introduce each term through a clear definition, followed by literary and colloquial examples, contextual interpretation, and practical exercises.

3.1. Teaching lexical stylistic devices through literary and colloquial examples

Lexical stylistic devices are particularly suitable for example-based instruction because their meanings can frequently be demonstrated through familiar expressions [16].

Metaphor

Metaphor is a stylistic device based on an implicit comparison between two phenomena that share certain characteristics. It transfers meaning from one conceptual domain to another.

Literary example:

William Shakespeare's famous expression from As You Like It (Act II, Scene VII):

"All the world's a stage."

In this metaphor, the world is represented as a stage, while human life is compared to a theatrical performance. The expression communicates the idea that people perform different roles throughout their lives.

Colloquial examples:

- "I'm drowning in work."
- "She has a heart of stone."
- "Time is money."

In everyday communication, these expressions make abstract experiences more vivid. The first example communicates an overwhelming amount of work, while the second describes an emotionally insensitive person.

Teaching recommendation: Students can be asked to identify the literal and figurative meanings of each expression and explain why the speaker chooses a metaphor instead of a direct statement.

Simile

Simile is a figure of speech in which two different objects, people, or phenomena are explicitly compared, usually through words such as like or as.

Literary example:

In Shakespeare's Sonnet 18, the speaker begins:

"Shall I compare thee to a summer's day?"

The comparison with a summer's day establishes the poem's central discussion of beauty and permanence.

Colloquial examples:

- "He is as brave as a lion."
- "She runs like the wind."
- "It is as cold as ice."

These expressions demonstrate how similes contribute to ordinary communication by making descriptions more understandable and expressive.

Teaching recommendation: Teachers can ask students to transform ordinary sentences into similes. For example:

- Ordinary: "He is very strong."
- Figurative: "He is as strong as an ox."

This exercise helps students understand the relationship between direct description and figurative comparison.

Personification

Personification involves attributing human characteristics, emotions, or actions to non-human objects, animals, or abstract concepts.

Literary example:

William Wordsworth's poem I Wandered Lonely as a Cloud contains the expression:

"Fluttering and dancing in the breeze."

The description of daffodils as dancing creates a lively image of nature.

Colloquial examples:

- "My alarm clock hates me."
- "The wind is whispering."
- "The sun is smiling."

These expressions illustrate the use of human characteristics to describe natural phenomena and everyday objects.

Teaching recommendation: Students can be encouraged to describe ordinary objects as if they were human beings. This activity develops imagination and demonstrates the expressive potential of personification.

Hyperbole

Hyperbole is an intentional exaggeration used to emphasize an idea, emotion, or situation.

Literary example:

In Shakespeare's Macbeth, the expression:

"Will all great Neptune's ocean wash this blood Clean from my hand?"

uses an exaggerated image to communicate Macbeth's overwhelming guilt.

Colloquial examples:

- "I've told you a million times."
- "I'm dying of hunger."
- "This bag weighs a ton."

In these examples, exaggeration communicates emotional intensity rather than factual information.

Teaching recommendation: Students should distinguish between literal and exaggerated meanings. They can also identify situations in which hyperbole is appropriate, such as informal conversations, humorous stories, and emotional descriptions.

Irony

Irony occurs when the intended meaning differs from the literal meaning of an expression [2]. It frequently depends on context, tone, and shared knowledge between speakers.

Literary example:

In Jane Austen's Pride and Prejudice, the opening sentence states:

"It is a truth universally acknowledged, that a single man in possession of a good fortune, must be in want of a wife."

The statement is ironic because it humorously reflects the social expectations and marriage-related concerns of the society depicted in the novel.

Colloquial examples:

- "Wonderful weather!" said during heavy rain.
- "Great job!" after someone makes an obvious mistake.
- "That's exactly what I needed!" when something unpleasant happens.

Teaching recommendation: Teachers should emphasize that irony cannot always be identified through vocabulary alone. Students must examine the situation, speaker's intention, and tone of voice.

3.2. Teaching syntactical stylistic devices through authentic communication

Syntactical stylistic devices demonstrate how sentence structure can contribute to expressiveness and emphasis.

Repetition

Repetition involves the intentional recurrence of words, phrases, or grammatical structures.

Literary example:

In Martin Luther King Jr.'s speech I Have a Dream, the repeated expression "I have a dream" creates rhythm, emotional intensity, and rhetorical emphasis.

Colloquial examples:

- "Never, never, never give up!"
- "I called you and called you."
- "Why, why, why did you do that?"

Repetition is frequently used in everyday conversations to express frustration, excitement, insistence, or emotional involvement.

Teaching recommendation: Students can compare a sentence containing repetition with its non-repetitive equivalent.

For example:

- "I want you to listen."
- "I want you to listen, listen carefully!"

This comparison illustrates how repetition strengthens emphasis.

Rhetorical question

A rhetorical question is a question that does not necessarily require an answer because its purpose is to emphasize an idea or influence the listener.

Literary example:

In Shakespeare's The Merchant of Venice, Shylock asks:

"Hath not a Jew eyes?"

The question emphasizes shared humanity and challenges discriminatory attitudes.

Colloquial examples:

- "Who doesn't want to be successful?"

- "Do I look like I have unlimited time?"
- "What could possibly go wrong?"

Teaching recommendation: Students should identify whether a question requests information or performs an expressive and persuasive function.

Ellipsis

Ellipsis refers to the omission of elements that can be understood from the context.

Literary example:

In Ernest Hemingway's prose, concise dialogue and the omission of explanatory material often require readers to infer meaning from context.

Colloquial examples:

- "Coming?"
- "Want some coffee?"
- "Seen him lately?"

These expressions demonstrate how speakers frequently omit grammatical elements in informal communication without losing the intended meaning.

Teaching recommendation: Students can reconstruct the complete grammatical forms of elliptical expressions and compare them with their shortened conversational equivalents.

3.3. Teaching phonetic stylistic devices through sound patterns

Phonetic stylistic devices are especially important in poetry, advertising, slogans, and expressive everyday language.

Alliteration

Alliteration is the repetition of identical or similar consonant sounds at the beginning of neighboring or closely connected words.

Literary example:

The opening line of Samuel Taylor Coleridge's The Rime of the Ancient Mariner contains:

"The fair breeze blew, the white foam flew."

The repetition of the /b/ and /f/ sounds contributes to the musical organization of the line and reinforces its descriptive quality.

Colloquial examples:

- "Big brown bear."
- "Peter Piper picked a peck of pickled peppers."
- "Busy bees buzz."

Assonance

Assonance involves the repetition of similar vowel sounds within nearby words.

Literary example:

In Edgar Allan Poe's The Raven, the repetition of long vowel sounds contributes to the poem's musicality and atmosphere.

Colloquial examples:

- "Go slow."
- "Try to find the right time."
- "The rain in Spain stays mainly in the plain."

Onomatopoeia

Onomatopoeia refers to words that imitate or suggest natural sounds.

Literary examples:

- "Buzz"
- "Hiss"
- "Crash"
- "Whisper"

Colloquial examples:

- "The door went bang!"
- "The phone went beep."
- "The water splashed."

Teaching recommendation: Students can listen to examples, identify repeated sounds, and explain how sound contributes to meaning. Audio materials, pronunciation exercises, and short recordings of everyday conversations can make this activity more effective [8].

3.4. Comparative analysis of literary and colloquial stylistic expressions

One of the most productive ways of teaching stylistic terminology is to present literary and colloquial examples side by side. This method enables students to understand that stylistic devices are not exclusive to literary texts.

The following table illustrates how selected stylistic devices function in different communicative environments.

Stylistic device	Literary example	Colloquial example
Metaphor	"All the world's a stage."	"I'm drowning in work."
Simile	Comparison with a summer's day in Shakespeare	"He is as brave as a lion."
Personification	Daffodils dancing in Wordsworth	"My computer hates me."
Hyperbole	Macbeth's image of Neptune's ocean	"I've told you a thousand times."
Irony	Opening sentence of Pride and Prejudice	"Wonderful weather!" during a storm
Repetition	"I have a dream"	"I called and called."
Rhetorical question	"Hath not a Jew eyes?"	"Who doesn't want success?"
Alliteration	"The fair breeze blew"	"Busy bees buzz."
Onomatopoeia	Sound-imitative words in poetry	"The door went bang!"

The comparison reveals that the same stylistic device can perform different communicative functions depending on the context.

In literary texts, stylistic devices frequently contribute to characterization, symbolism, atmosphere, thematic development, and aesthetic organization [14]. In colloquial speech, their principal functions often include emotional expression, emphasis, humor, persuasion, and interpersonal communication [10].

This distinction is important because students should not merely identify a stylistic device but also explain why it is used in a particular situation.

3.5. Teaching euphemism and metonymy through everyday communication

In addition to commonly taught figurative devices, euphemism and metonymy deserve particular attention because they demonstrate the relationship between language, culture, and social interaction.

Euphemism

A euphemism is a mild or indirect expression used instead of one that may be considered unpleasant, embarrassing, or socially inappropriate.

Literary examples:

- "Passed away" instead of "died."
- "Resting in peace" as a respectful reference to death.

Colloquial examples:

- "Between jobs" instead of "unemployed."
- "Let go" instead of "dismissed."
- "A little overweight" instead of a more direct description.

Teaching euphemisms helps students understand politeness, social conventions, and the influence of cultural expectations on language [15].

Metonymy

Metonymy is a stylistic device in which an object or concept is referred to through the name of something closely associated with it.

Literary example:

In Shakespeare's Julius Caesar, the expression "lend me your ears" refers to giving attention rather than physically lending one's ears.

Colloquial examples:

- "The crown issued a statement." (The monarchy or monarch.)
- "The press reported the incident." (Journalists or news organizations.)
- "Hollywood is changing." (The American film industry.)

Teaching recommendation: Students should identify the relationship between the literal expression and the intended referent. This activity strengthens their understanding of semantic associations and figurative meaning.

3.6. Practical teaching activities and classroom exercises

The results of the pedagogical analysis suggest that stylistic terminology should be introduced through activities that require active student participation.

The following classroom techniques can be incorporated into stylistics courses.

Activity 1: Identify the stylistic device

Students receive a collection of sentences and identify the stylistic devices used in them.

Examples:

1. "The stars danced in the sky."
2. "I'm so hungry I could eat a horse."
3. "Life is a journey."
4. "She sells seashells by the seashore."
5. "What a beautiful day!" (said during a terrible storm.)

Expected answers:

1. Personification.
2. Hyperbole.
3. Metaphor.
4. Alliteration.
5. Irony.

Activity 2: Literary versus colloquial language

Students compare two expressions containing the same stylistic device.

Example:

- Literary: "The moon was a ghostly galleon tossed upon cloudy seas." (Alfred Noyes, The Highwayman).
- Colloquial: "My mind is a complete mess."

Students discuss the similarities and differences in their expressive functions.

Activity 3: Complete the metaphor

Students are provided with incomplete expressions and asked to create meaningful metaphors.

Examples:

- Knowledge is ...
- Time is ...
- Love is ...
- Education is ...

Possible answers include:

- Knowledge is a key.
- Time is a thief.
- Love is a journey.
- Education is a bridge.

Activity 4: Transform ordinary sentences into figurative expressions

Students are asked to rewrite ordinary sentences using different stylistic devices.

Ordinary sentence	Possible transformation
The weather is very cold.	It is as cold as ice.
He is very angry.	He is boiling with anger.
She is very beautiful.	She is a ray of sunshine.
The wind is blowing strongly.	The wind is roaring through the streets.
I have a lot of work.	I'm drowning in work.

Activity 5: Analyze a short literary passage

Students select a short paragraph from a novel, poem, or short story and identify the stylistic devices used by the author.

They should explain:

1. Which stylistic devices are present?
2. What linguistic features indicate their presence?
3. What meanings do they communicate?
4. How do they influence the reader?
5. Could the same devices be used in everyday conversation?

This activity encourages students to move beyond memorizing definitions and develop independent analytical skills.

4. Discussion

The findings demonstrate that teaching stylistic terminology requires an approach that combines linguistic theory with practical language analysis. Traditional methods that rely exclusively on memorizing definitions may provide students with basic theoretical knowledge, but they do not necessarily develop the ability to recognize stylistic devices in authentic communication.

The integration of literary and colloquial examples offers several pedagogical advantages.

First, it makes abstract linguistic concepts more accessible. Students often understand stylistic devices more easily when they encounter them in familiar conversational expressions before analyzing more complex literary examples. For instance, the expression I'm drowning in work provides an accessible introduction to metaphor before students examine Shakespeare's All the world's a stage.

Second, comparative teaching improves students' understanding of register. Literary and colloquial language differ in their communicative purposes, structural characteristics, and degrees of conventionality. Biber and Conrad (2009) emphasize the importance of examining language variation in relation to register, genre, and communicative context [5]. This perspective supports the inclusion of different language varieties in stylistics instruction.

Third, contextual analysis encourages students to understand the relationship between linguistic form and communicative intention. Irony, euphemism, hyperbole, and rhetorical questions cannot always be interpreted accurately through isolated sentences. Their meanings frequently depend on situational circumstances, cultural knowledge, and the relationship between participants [11].

The importance of contextualized stylistic analysis is also supported by Leech and Short (2007), who demonstrate how linguistic choices contribute to literary interpretation [13]. Their

approach indicates that stylistic devices should be examined in relation to their textual functions rather than treated as independent decorative elements.

Another important aspect is the development of students' interpretative abilities. Literary texts offer opportunities to examine how writers use language to construct characters, express emotions, and establish particular perspectives. Penny (2011) argues that applied stylistic approaches can help learners understand the relationship between linguistic choices and literary interpretation.

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Similarly, Simpson's (1992) research on teaching stylistics demonstrates the educational value of practical activities that require students to reconstruct and analyze narrative organization [17]. His approach illustrates that active engagement with literary texts can provide insights into linguistic structure and function that may not emerge through traditional explanation alone.

Paul Simpson, 1992+1

The present study also highlights the importance of colloquial speech as a teaching resource. Everyday expressions provide authentic opportunities to examine how stylistic devices function in spontaneous communication. For example, hyperbole is frequently used to communicate strong emotions, while metaphors can simplify abstract ideas and make descriptions more vivid.

Nevertheless, teachers should avoid presenting every figurative or expressive expression as a stylistic device without considering its context. Some metaphors and idiomatic expressions have become conventionalized in everyday language. Their original figurative character may be less noticeable to speakers. Therefore, students should be encouraged to distinguish between conventional expressions and deliberately expressive language.

Furthermore, teaching stylistic terminology should take into account differences in students' linguistic proficiency. Beginners may benefit from simple examples and visual explanations, whereas advanced students can analyze longer literary passages, compare different registers, and investigate the interaction of several stylistic devices within a single text.

Digital resources can also strengthen the teaching process. Short videos, audio recordings, electronic literary texts, online dictionaries, and linguistic corpora provide opportunities to examine stylistic phenomena in different communicative environments. Such materials are particularly useful for analyzing pronunciation, intonation, repetition, and other features of spoken language.

An additional consideration concerns the relationship between stylistics and communicative competence [18]. Students who understand stylistic devices can make more appropriate linguistic choices depending on their communicative objectives. They become more aware of how expressions may influence listeners, create emotional responses, and establish interpersonal relationships.

The proposed approach therefore treats stylistics not merely as a theoretical branch of linguistics but also as a practical means of improving language awareness, interpretation, and communication.

However, the study has certain limitations. It presents a qualitative pedagogical analysis rather than an experimentally tested teaching intervention. No controlled classroom experiment or quantitative measurement of learning outcomes was conducted. Further research could compare traditional definition-based instruction with contextualized, example-based instruction among different groups of language learners. Such research would provide empirical evidence concerning the effectiveness of the proposed methods.

5. Conclusion

Teaching stylistic terminology through literary and colloquial examples represents an effective approach to developing students' linguistic awareness and interpretative competence. The study demonstrates that stylistic devices become easier to understand when theoretical definitions are accompanied by examples that illustrate their functions in different communicative contexts.

The analysis identifies several important pedagogical principles. First, stylistic terms should be introduced through clear definitions and accessible examples. Second, literary and colloquial expressions should be compared to demonstrate how the same linguistic device can perform different functions. Third, contextual interpretation should be emphasized because stylistic meaning frequently depends on communicative intention and situational circumstances. Finally, practical exercises should encourage students to identify, analyze, and independently produce stylistically expressive language.

The investigation also confirms the educational value of combining lexical, syntactical, semantic, and phonetic stylistic devices within a unified teaching framework. Activities such as identifying figurative expressions, transforming ordinary sentences, comparing literary passages, and analyzing conversational examples can make stylistics instruction more interactive and meaningful.

In conclusion, stylistic terminology should not be taught simply as a collection of theoretical definitions. It should be presented as a practical system for understanding how language creates meaning, communicates emotions, and produces aesthetic and rhetorical effects. The integration of literature and colloquial speech provides students with a broader understanding of stylistic variation and helps them apply theoretical knowledge to real communicative situations [7].

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A Contrastive Approach to Teaching Persian Ezafe to University Beginners in Azerbaijan

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Abstract This article proposes two lessons on Persian Ezafe for first-year university students whose first language is Azerbaijani. It focuses on singular nouns ending in a consonant, followed by an attributive adjective or an overt nominal possessor. In the corresponding Azerbaijani phrases, the adjective or possessor precedes the noun, whereas in Persian it follows the noun and is linked to it by the vowel *-e*. The vowel is usually unmarked in ordinary writing. The lessons use these differences to guide listening, comparison of the two languages, reading aloud, and a paired task in which students identify lost items and their owners. A proposed assessment distinguishes word order from the oral realization of Ezafe and checks whether learners can apply the patterns to new combinations of familiar words. The article presents an instructional design and a protocol for its classroom evaluation.

Keywords Persian as a foreign language, Ezafe, Azerbaijani-speaking learners, form-focused instruction, university language teaching

Introduction

A beginning learner who encounters کتاب سبز in a Persian text has to supply the vowel that links the two written words. To say ‘green book ’from a picture, the learner also has to choose the order of those words. Reading a phrase and producing one from a visual cue therefore place different demands on the learner. This distinction matters in a university class where the students already recognize basic Persian words and can benefit from practice in combining them into phrases.

Ezafe links a noun to a following adjective or nominal possessor in the constructions considered here (Samvelian, 2007). The corresponding Azerbaijani phrases provide a useful point of comparison because they express familiar relationships in a different order and, in possessive phrases, with different morphology (Garibova & Aliyeva, 2024). An instructor can use these contrasts to decide which forms to model, which errors to distinguish in feedback, and which tasks to use when checking progress. The contrast also allows the teacher to give the explanation using familiar Azerbaijani examples while keeping the classroom task in Persian.

The question guiding this article is how differences between the two languages can inform a lesson sequence for reading and producing Persian adjective and possessive phrases. The intended learners are first-year university students in Azerbaijan at the end of an introductory A1 course who can read basic Persian script. The proposed materials assume a small vocabulary of objects, colors, and personal names. A description of the target structures precedes the design of two 45-minute lessons and a short classroom assessment.

Persian and Azerbaijani Noun Phrases

In the Iranian Persian patterns taught here, the head noun comes first. In کتابِ سبز *ketāb-e sabz*‘ green book’, the adjective *sabz* follows the noun *ketāb*. In کتابِ مریم *ketāb-e Maryam* ‘Maryam’s book’, the name follows the noun denoting the possessed object. Both phrases contain the same linking vowel *-e*. The adjective and the possessor are distinguished by their grammatical

function and meaning, while the position and pronunciation of the linker are the same (Samvelian, 2007).

Table 1

Adjective and Possessive Phrases in Persian and Azerbaijani

Construction	Persian	Azerbaijani	English
Adjective	کتابِ سبز *ketāb-e sabz*	*yaşıl kitab*	green book
Possessive	کتابِ مریم *ketāb-e Maryam*	*Məryəmin kitabı*	Maryam's book

In the Azerbaijani equivalent *yaşıl kitab*, the adjective precedes the noun. In *Məryəmin kitabı*, the possessor *Məryəm-in* precedes the possessed noun *kitab-ı*. The genitive suffix *-in* marks the possessor, and the third-person possessive suffix *-ı* marks the possessed noun (Garibova & Aliyeva, 2024). Placing these forms beside the Persian examples makes it possible to ask two different questions about an attempted Persian phrase. Where did the learner place the head noun? Did the learner pronounce *-e* after it? Reversed order is a plausible transfer error, although the structural comparison alone cannot establish its frequency or its cause in a particular class.

In ordinary Persian spelling, short vowels are generally omitted. After a consonant, Ezafe can be shown with a kasre in teaching materials, as in کتابِ سبز. In an unmarked text, کتاب سبز represents the same phrase (The University of Texas at Austin, n.d.). Learners therefore need experience reading both versions. The class also distinguishes an attributive phrase from a short predicative clause, as in کتابِ سبز *ketāb-e sabz*' green book 'and کتاب سبز است *ketāb sabz ast*' the book is green'. This comparison sets a boundary on the classroom rule and gives the teacher a way to check whether a learner extends *-e* to every sequence of a noun and an adjective.

The lesson uses a single dependent per noun phrase and keeps all head nouns consonant-final. Persian also has other realizations and longer sequences of linked elements (Samvelian, 2007). Restricting the examples to these two patterns allows the class to work with one pronunciation and one position for the linker while comparing two grammatical relationships.

Pedagogical Rationale

Form-focused instruction in this design means planned attention to a grammatical feature during a sequence that includes a communicative task. Explicit comparison serves an immediate purpose in this setting. Students already know the concepts of description and possession in Azerbaijani, so the teacher can use that knowledge to direct attention to the corresponding Persian word order. Modeling the Persian phrases before showing the spelling gives students an opportunity to hear a vowel that ordinary print may leave implicit. Guided production then requires them to retrieve the pattern with a reason to use it.

Ellis (2006) discusses how grammar instruction can be integrated into a communicative curriculum. Spada and Tomita (2010) report advantages for explicit instruction across the English grammatical features included in their meta-analysis. These studies inform the choice to give a short explanation before students use the forms to exchange information. The broader account of Persian materials and assessment by Shabani-Jadidi and Sedighi (2018) provides a context for adapting this choice to a specific group of learners and a feature of Persian script.

Naghizade and Sahraei (2026) examined Persian Ezafe with Iraqi Arabic-speaking learners using tasks that included reading aloud and sentence completion. Their study provides a precedent for examining the same feature through more than one task. The present design uses the comparison between Azerbaijani and Persian to determine the content of instruction and separates reading aloud from prompted oral production. It treats word order and pronunciation as observable features that can develop at different rates.

Classroom Sequence

The teacher prepares pictures of familiar objects, loose Persian word cards, and two versions of a short phrase sheet. The first version marks Ezafe with a kasre, and the second uses ordinary spelling. The teacher can provide spoken models live or record them in advance. Students should already recognize words such as کتاب *ketāb*‘ book’, دفتر *daftar*‘ notebook’, مداد *medād* ‘pencil’, and کیف *kif*‘ bag ’in isolation. The teacher checks familiarity with the objects, colors, and names in isolation before the baseline assessment. To reserve the combinations in Table 2 for assessment, classroom practice uses black and white objects and the names Mina and Hamed alongside the two examples in Table 1.

The First Lesson

The first lesson begins with a five-minute vocabulary check using pictures. In the next eight minutes, the teacher says pairs such as *ketāb* and *ketāb-e sabz* without showing the text. Students signal when they hear *-e*, then identify the word after which it occurs. A second pair, *ketāb* and *ketāb-e Maryam*, lets them check that the same sound occurs in a phrase expressing ownership.

The teacher spends the next ten minutes displaying the Persian phrases alongside their Azerbaijani equivalents. Students point to the noun being described or possessed in each phrase and explain where it occurs. The teacher states the classroom rule in terms of the patterns in Table 1. The following ten minutes are devoted to assembling and saying phrases using separate noun, adjective, and name cards. Learners place the noun first, read the pair aloud, and exchange cards to make another phrase. A brief predicative example gives the class a chance to decide whether the sound belongs in a given context.

In the final twelve minutes, students read a short set of phrases first with and then without kasre. The second sheet changes the order of the items so students have to read the phrase they see. The teacher can then show a new picture and ask for the corresponding phrase without providing a written model. If the words appear in the target order but the vowel is missing, the teacher points to the boundary after the noun and asks the student to say the phrase again.

The Second Lesson

The first five minutes are used to retrieve the patterns from pictures and names. During the next eight minutes, the teacher models a lost-property exchange. Student A has numbered pictures showing a black book, a white book, a black bag, and a white bag. Student B has a record that connects each item to an owner. In one version, Mina owns the white book and black bag, and Hamed owns the black book and white bag. The record uses icons and names so it can be consulted without reading a complete phrase. Because two items share each object type and two share each color, the description must specify both the noun and its adjective for an accurate match.

The pairs have twenty minutes to complete the exchange and switch roles with a second set. Student A identifies an item by saying, for example, کتابِ سفید *ketāb-e sefid*‘ white book’. Student B consults the record and answers with an ownership phrase such as کتابِ مینا *ketāb-e Minā*‘ Mina’s book’. Student A records the owner beside the correct picture. The teacher asks students to name the object in both turns so that an isolated color or personal name does not replace the target phrase. A word bank provides individual nouns, colors, and names when needed. The exchange requires students to use both target structures for a single purpose and gives them a record they can check at the end.

In the last twelve minutes, the class checks the matches and revisits a few phrases drawn from the activity. The teacher responds to reversed order by asking which word denotes the item and having students place it first. When *-e* is missing in a correctly ordered phrase, the teacher prompts students to repeat the noun with the linker before completing the phrase. If a prompt fails to elicit a repair, the teacher models the whole phrase and asks the learner to apply the pattern to a different item.

Classroom Assessment

The proposed checks take place before the first lesson, immediately after the second lesson, and one week after the second lesson. Each check includes four phrases to produce orally from pictures and ownership cues and four phrases to read aloud in unmarked script. Each task contains two adjective phrases and two possessive phrases. A colored object cues the adjective phrase, and a picture of an object beside a personal name cues the possessive phrase. The teacher asks the student to respond with a complete noun phrase in Persian and presents the production cards before the reading sheet so the printed phrases do not model the structure immediately before elicitation. Table 2 varies the combinations of familiar words across the three checks.

Table 2

Sample Items for Three Classroom Checks

Check	Reading in unmarked Persian script	Cues for oral production
A	دفتر قرمز | کتاب آبی کیف مریم | مداد علی	yellow pencil, green bag Sara’s book, Reza’s notebook
B	دفتر زرد | کتاب قرمز کیف سارا | مداد مریم	green pencil, blue bag Reza’s book, Ali’s notebook
C	دفتر سبز | کتاب زرد کیف رضا | مداد سارا	blue pencil, red bag Ali’s book, Maryam’s notebook

The teacher presents one item at a time and uses the same instructions at each check. For a classroom evaluation of the sequence, the teacher defers feedback on the assessment items until after the delayed check and records any practice with Ezafe between checks. In reading aloud, the teacher records whether *-e* is audible after the noun and before the dependent. In prompted production, the teacher first records whether the learner places the noun first. For responses in the target order, the teacher then records whether the linker occurs in the expected position. An item that elicits a bare noun, a response with different target words, or no response is recorded separately from an item with a word order error. A bare noun and a short predicative clause can be added as unscored checks for overuse of the linker.

For each check, the teacher reports the number of reading items with Ezafe, the number of interpretable production responses in the target order, and the number of correctly ordered responses with Ezafe, with their respective denominators. An optional count of fully correct production responses out of four retains a common denominator for a descriptive comparison across occasions. Recording both the item type and the response makes it possible to see whether a learner handles adjective and possessive phrases differently. With two items of each type per task, such differences are diagnostic observations for follow-up practice.

Interpretation and Limitations

A learner who reads *-e* accurately but omits it during prompted production may need more practice retrieving the form without a written cue. A learner who repeatedly reverses word order may benefit from reconstructing examples with cards. Results from these short tasks would describe performance on the two target structures. The forms should be piloted for comparable difficulty. In a study with several groups, their order can be rotated so each form serves at different time points. A delayed check with new combinations tests whether learners can extend the pattern beyond the practiced phrases, though repeated exposure to the task may itself influence performance. Evidence of sustained use in spontaneous speech would require additional tasks. A comparison with another teaching sequence would be needed to estimate any advantage attributable to this design.

Conclusion

The proposed sequence uses a specific difference between Persian and Azerbaijani to organize classroom instruction. It makes *-e* audible before students encounter it in ordinary print and gives them a reason to use both target phrases in a short exchange. Separate scores for word order and the spoken linker give teachers a basis for deciding which part of the construction requires further practice. The sequence and its assessment provide a starting point for classroom evaluation with Azerbaijani-speaking university beginners.

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SÜNİ İNTELLEKTLƏ HÜQUQİ TƏRCÜMƏDƏ AXICILIQ VƏ MƏNA DƏQİQLİYİ

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Abstract

Generative artificial intelligence can produce fluent Persian drafts of Azerbaijani legal sentences, but fluency alone does not establish that legal meaning has been preserved. This theoretical article develops a clause-level contrastive reading procedure for examining that distinction. It draws on legal translation scholarship and translation quality assessment frameworks, without testing any particular system. The analysis focuses on five relations that may be altered without making the Persian sentence ungrammatical: obligation and permission, the roles of legal actors, the order of events, negation, and the scope of a restrictive expression. Five short Azerbaijani–Persian pairs constructed for this article compare a meaning-preserving formulation with a fluent alternative that expresses a different rule. These pairs are analytical illustrations rather than recorded AI outputs, so they support no claim about the frequency of model errors. The proposed procedure begins by identifying the actor, action, modal force, condition, negation, and restriction in the Azerbaijani source. The reviewer then checks whether the same relations hold in the Persian draft before considering stylistic naturalness and terminology. The article's contribution is a limited and teachable way to distinguish target-language fluency from source–target meaning correspondence. It can structure the review of AI-assisted legal translation drafts and classroom discussion, while leaving full-document interpretation and empirical model evaluation to further work.

Keywords: artificial intelligence; legal translation; fluency; meaning accuracy; Azerbaijani; Persian

Giriş

Süni intellektlə tərcümə alətləri hüquqi mətnin farsca ilkin variantını qısa müddətdə hazırlaya bilir. Bu, xüsusən oxucuya Azərbaycan dilindəki sənəd haqqında ümumi təsəvvür vermək lazım gəldikdə faydalıdır. Lakin tərcüməni oxuyan adamın gördüyü ilk keyfiyyət çox vaxt cümlələrin təbiiliyidir. Farsca mətn düzgün yazılıbsa və fikirlər rahat izlənirsə, onun mənbə ilə dəqiq uyğun gəldiyi düşünülə bilər. Hüquqi mətn üçün belə nəticəyə təkcə axıcılıq əsasında gəlmək olmaz. Cümlənin qrammatik baxımdan qüsursuz olması onda kimin hüquqa malik olduğunu, kimin hansı vəzifəni daşıdığını və ya şərtin nə vaxt qüvvəyə mindiyini göstərmir.

Tutaq ki, Azərbaycan dilində bir tərəfin müəyyən sənədi təqdim edə biləcəyi yazılıb. Farscada həmin fikir təbii səslənən, lakin təqdimatı məcburi göstərən cümlə ilə əvəz edilirsə, oxucu tərcümənin dilində problem görməyə bilər. Bununla belə, mənbədəki icazə və hədəf mətndəki öhdəlik eyni hüquqi məna daşımır. Oxşar fərq inkarın itməsi, işçi ilə işəgötürənin yerinin dəyişməsi, yaxud «yalnız» sözünün əhatə dairəsinin dəyişməsi zamanı yaranır. Bu məqalənin predmeti tərcümə səthində görünməyən həmin məna fərqləridir.

Hüquqi tərcümənin keyfiyyəti haqqında geniş ədəbiyyat mövcuddur. Prieto Ramos (2015) hüquqi mətnin tərcüməsini məqsəd, hüquqi mühit, mətn növü və terminoloji seçimlə birlikdə dəyərləndirir. Bajčić və Golenko (2024) böyük dil modellərinin hüquqi tərcümədə tətbiqinə dair araşdırmaların, xüsusən terminologiya və müxtəlif dil cütləri baxımından, genişləndirilməsinə ehtiyac olduğunu göstərirlər. Bu nəzəri iş həmin müzakirəni dar bir suala yönəldir: axıcı farsca cümlə hansı hallarda Azərbaycan dilindəki hüquqi münasibəti başqa şəkildə ifadə edə bilər?

Azərbaycan–fars istiqamətinin seçilməsi yalnız iki dil arasındakı söz fərqləri ilə izah olunmur. Azərbaycan dilindəki hüquqi qayda farsca oxucuya çatdırılarkən onu başqa bir ölkənin qanunu kimi deyil, mənbə sisteminə aid məlumat kimi təqdim etmək lazımdır. Bu zaman fars dilinin təbii ifadə imkanlarından istifadə etmək olar, amma Azərbaycan mətnindəki şərt və hüquqi tərəflər dəyişməməlidir. Məsələnin mərkəzində buna görə hazır bir termin siyahısı yox, mənbədə ifadə olunan münasibətin hədəf mətndə qorunması dayanır. Aşağıda verilən nümunələr də hər iki dili əhatə edən bu oxu vərdişini izah edir.

Məqalənin məqsədi Azərbaycan–fars istiqamətində hüquqi tərcüməyə baxarkən axıcılığı və məna dəqiqliyini ayrıca yoxlamağın səbəbini izah etməkdir. İşdə İran hüququ ilə Azərbaycan hüququ müqayisə edilmir; fars dili yalnız hədəf dil kimi götürülür. Burada institusional məsuliyyət modeli deyil, cümlə səviyyəsində yoxlanıla bilən beş məna əlaqəsi diqqət mərkəzindədir. Təhlildə məqalə üçün qurulmuş qısa nümunələrdən istifadə olunur; hər hansı modelin səhv tezliyi ölçülmür.

Ədəbiyyat icmalı və nəzəri əsas

Tərcümədə axıcılıq hədəf dil mətninin qrammatik və üslubi baxımdan təbii səslənməsinə aiddir. Məna dəqiqliyi isə mənbə ilə hədəf arasında qurulan münasibətdir: hərəkət, tərəf, şərt və nəticə dəyişmədən ötürülübmü? Bu xüsusiyyətləri eyni meyar kimi dəyərləndirmək metodoloji səhv yaradır. Multidimensional Quality Metrics (MQM) çərçivəsində terminologiya, mənbə–hədəf uyğunluğu və hədəf dilin linqvistik normaları ayrıca xəta ölçüləridir (MQM Council, n.d.). Bu bölgü məqalənin başlanğıc nöqtəsidir: oxucu yalnız farsca mətni görməklə onun Azərbaycan dilindəki mənbəyə sədaqətini tam müəyyənləşdirə bilməz.

Hüquqi məna təkcə ayrı-ayrı terminlərdən ibarət deyil. Müəyyən sözlərin cümlə daxilində qurduğu əlaqə də önəmlidir. «Borcludur» öhdəlik bildirir; «edə bilər» isə kontekstdən asılı olaraq hüquq, səlahiyyət və ya imkan ifadə edə bilər. Əməliyyatın baş verməsi üçün «əgər» ilə başlayan şərt qoyula, «yalnız» vasitəsilə həmin şərtin dairəsi məhdudlaşdırıla bilər. Biel (2014) tərcümə olunmuş hüquqi dildə deontik modallığı araşdırmaqla məcburiyyət və imkan bildirən formaların hüquqi mətnə məxsus bir təhlil sahəsi olduğunu göstərir. Onun tədqiqatı Azərbaycan–fars cütlüyünə dair nəticə vermir; burada modallığa ayrıca diqqət yetirməyin nəzəri əsaslarından biri kimi istifadə edilir.

Hüquqi tərcümənin ümumi keyfiyyətini dəyərləndirərkən mətnin məqsədi və hüquqi konteksti də nəzərə alınmalıdır. Prieto Ramos (2015) terminlərin adi ikidilli lüğət qarşılığı ilə mexaniki əvəz edilməsini yetərli saymır; termin seçimi konkret hüquqi əlaqənin və istifadə şəraitinin içində qiymətləndirilməlidir. Hazırkı məqalə həmin geniş yanaşmadan yalnız məna qorunması ilə bağlı hissəni götürür. Beləliklə, qurumların məsuliyyəti, riskə görə iş bölgüsü və sənədin rəsmi təsdiqi kimi məsələlər burada ayrıca model şəklində araşdırılmır.

Bu məqalədə «hüquqi məna» ifadəsi ayrıca bir sözün lüğət mənasına endirilmir. Ərizənin verilməsi, bildirişin göndərilməsi, razılığın alınması kimi hərəkətlər cümlədə müəyyən iştirakçılar arasında yerləşir. Həmin hərəkətlərdən biri məcburi, icazəli və ya qadağan edilmiş ola bilər; birindən əvvəl başqa hadisənin baş verməsi tələb edilə bilər. Deməli, məna sözlərin toplandığı an yox, bu əlaqələr birgə oxunanda müəyyənləşir. Tərcüməçi bir termini düzgün seçib cümlənin məhdudiyyətini itirərsə, ayrıca termin düzgün olsa belə, bütöv hökm dəyişir. Bu səbəbdən terminoloji nəzarət və cümlə səviyyəsində məna nəzarəti bir-birini tamamlayır.

Süni intellekt və hüquqi tərcümə mövzusunda aparılmış tədqiqatlar bir-birindən fərqli alətləri, mətnləri və dil cütlərini əhatə edir. Moneus və Sahari (2024) ərəb–ingilis hüquqi mətnləri üzərində insan və süni intellekt tərcümələrini müqayisə edirlər. Giampieri (2023) isə italyan–ingilis müqavilə parçalarında maşın tərcüməsini araşdırır. Bu işlərin alət və dil cütləri eyni deyil; nəticələri birbaşa Azərbaycan–fars istiqamətinə köçürmək olmaz. Yeni dil cütlüyü haqqında faktiki nəticə yalnız ayrıca sınaqla əldə edilə bilər.

Freitag və həmkarları (2021) maşın tərcüməsinin insan tərəfindən qiymətləndirilməsində konkret xəta yerlərinin işarələnməsini tətbiq edirlər. ISO 5060:2024 isə insan, redaktə edilmiş

maşın və redaktəsiz maşın tərcüməsi məhsulunun xəta növləri ilə analitik qiymətləndirilməsinə dair ümumi göstərişlər verir (International Organization for Standardization, 2024). Bu mənbələr Azərbaycan–fars istiqamətinə aid təcrübə nəticəsi deyil; onlar mənbə ilə qarşılaşdırılaraq aşkarlanan fərqləri adlandırmağın metodik əsasını dəstəkləyir.

Generativ süni intellektlə ilkin tərcümənin yoxlanması

Böyük dil modelinə hüquqi cümləni farscaya çevirmək tapşırıldıqda, nəticə bütöv bir hədəf mətn kimi təqdim oluna bilər. Oxucu onun üzərində «düzgün tərcümə» etiketi ilə ayrıca təsdiq görmür; yalnız hazırlanmış cümləni görür. Bajčić və Golenko (2024) generativ alətlərin hüquqi terminologiya və mətnlər üçün potensialını müzakirə etməklə yanaşı, müxtəlif dillər və mətn növləri üzrə əlavə tədqiqatın vacibliyini vurğulayırlar. Bu məqalə həmin tədqiqatların yerini tutmur. Onun sualı daha məhduddur: ilkin variantın axıcılığı mənbə cümlədəki hüquqi əlaqənin saxlanıb-saxlanmadığını ayrıca yoxlamağa mane olmamalıdır.

Cavab tərcüməni sözbəsöz mətnə qaytarmaq deyil, hər iki cümlədə eyni əlaqələri ayrıca göstərməkdir. Mənbədə əvvəlcə tərəflər, hərəkət, öhdəlik və ya imkan, zaman şərti, inkar və məhdudiyyət müəyyənləşdirilir; sonra bunların farsca variantda qalıb-qalmadığı yoxlanır. Belə oxu insanın yazdığı variant üçün də yararlıdır, lakin generativ alətin sürətlə təqdim etdiyi səlis ilkin mətnlə işləyərkən ayrıca əhəmiyyət qazanır. Bu, alətin konkret səhvə meylli olduğunu sübut edən empirik iddia yox, məna müqayisəsini təşkil etmək üçün təklif olunan nəzəri prosedurdur.

Metodologiya

Məqalə nəzəri və keyfiyyət xarakterli kontrastiv təhlildir; sistematik ədəbiyyat icmalı və ya model sınağı deyil. Birinci addımda hüquqi tərcümə və keyfiyyət qiymətləndirməsinə dair mövzu ilə birbaşa bağlı mənbələr seçilir. İkinci addımda Azərbaycan dilində hüquqi münasibəti ifadə edən qısa cümlələr qurulur. Üçüncü addımda hər cümlə üçün mənanı qoruyan farsca ifadə və qrammatik baxımdan normal olsa da, hüquqi münasibəti dəyişən alternativ ifadə qarşılaşdırılır. Təhlil vahidi ayrıca söz yox, tərəf ilə hərəkət, şərt ilə nəticə və normativ qüvvə arasındakı əlaqədir.

Nümunələr bu məqalənin izah məqsədi üçün qurulmuşdur. Onlar Azərbaycan Respublikasının Əmək Məcəlləsindən sitat, hər hansı real müqavilədən çıxarış və ya süni intellekt sisteminin faktiki çıxışı deyil. «Səhv variant» ifadəsi burada konkret modelə aid iddianı yox, əgər belə yazılsa, hansı mənanın dəyişəcəyini göstərən düşüncə təcrübəsini bildirir. Buna görə də nümunələrdən tərcümə keyfiyyəti üzrə rəqəmlər, səhv tezliyi və ya modellər arasında üstünlük nəticəsi çıxarılmır.

Təhlil üçün beş yoxlama nöqtəsi seçilir: normativ qüvvə, tərəflərin rolu, zaman və şərt, inkar, məhdudlaşdırıcının əhatəsi. Bu seçim hüquqi mətnin bütün xüsusiyyətlərini əhatə edən yeni standart kimi təqdim edilmir. Məqsəd oxşar səslənən iki hədəf cümləsinin niyə eyni hüquqi informasiya vermədiyini nümayiş etdirməkdir. Nümunələrdəki «işçi» və farsca «کارگر» qarşılaşdırması da terminoloji norma müəyyən etmir; həqiqi sənəddə termin seçimi, hüquqi anlayış və təsdiq tələbləri ayrıca yoxlanmalıdır.

Bu seçim bir mühüm metodoloji məhdudiyyət də qoyur. Nümunədə hansı farsca variantın mənanı saxladığını göstərə bilmək, süni intellektin praktikada hansı variantı seçəcəyini əvvəlcədən bilmək demək deyil. Əlavə olaraq, ayrı cümlənin daxilində qurulmuş düzgün tərcümə bütün sənəd üçün yetərli olmaya bilər: başqa maddədə eyni terminə verilən tərif və ya əvvəlki bəndə göndəriş nəzərə alınmalıdır. Buradakı üsul tərcümə keyfiyyətini yekun qiymətləndirmə iddiası daşımır. O, mümkün dəyişikliklərin cümlə səviyyəsində hansı sualla tutulacağını göstərir.

Axıcılıq və məna dəqiqliyinin ayrılması

Axıcılıq bir cümlənin öz daxilində dəyərləndirilə bilər. Oxucu farsca söz sırasının və fel formasının təbii olub-olmadığını çox vaxt Azərbaycan dilindəki mənbəni görmədən də müəyyən edir. Məna dəqiqliyini yoxlamaq üçün isə iki mətn birlikdə oxunmalıdır. Mənbədəki «kim nə edir?» sualının cavabı hədəfdə dəyişibsə, farsca mətn mükəmməl səslənsə belə, hüquqi münasibət dəyişmiş sayılır. Bu fərq sadə görünür, lakin praktik oxu zamanı axıcı mətn yoxlayıcının diqqətini forma üzərinə çəkə bilər.

Yaxşı tərcümə yalnız sözlərin üst-üstə düşməsi demək deyil. Azərbaycan və fars dillərində eyni mənanı təbii ifadə etmək üçün cümlənin quruluşunu dəyişmək mümkündür. Burada yoxlama obyektini məhz buna görə söz-söz eynilik deyil, münasibətlərin sabitliyi təşkil edir. Azərbaycan dilində işçinin hansı hüquqa malik olduğu farscada başqa sintaksislə verilə bilər; vacib olan hüquq sahibinin və hərəkətin statusunun dəyişməməsidir. Bu yanaşma sərbəst ifadə ilə məna itkisini fərqləndirməyə kömək edir.

Məna dəyişməsi hər zaman diqqətçəkən sözlə baş vermir. «Yalnız»ın «həmçinin» kimi verilməsi, «sonra»nın «əvvəl»ə çevrilməsi, yaxud inkar hissəciyinin düşməsi hədəf cümləni qrammatik cəhətdən pozmur. Əksinə, nəticədə tamamilə oxunaqlı yeni bir cümlə alınır. Tərcüməçi üçün çətinlik məhz buradadır: üslubun rahatlığı həmin kiçik vahidlərin yaratdığı nəticəni gizlədə bilər.

Axıcılığın səhvə səbəb olduğunu iddia etmək də doğru olmazdı. Süni intellekt həm mənbə mənasını saxlayan, həm də təbii səslənən cümlə qura bilər. Burada təhlil edilən məsələ qiymətləndirmə üsuludur: hədəf mətni tək oxuyaraq verilən müsbət hökm mənbəyə uyğunluq haqqında hələ məlumat vermir. İki sual ardıcıl qoyulmalıdır. Əvvəl farsca cümlənin öz dilində başadüşülən olub-olmadığı soruşulur. Sonra onun Azərbaycan mətnindəki qaydanı ifadə edib-etmədiyi müqayisə yolu ilə araşdırılır. Bu sualların cavabları təsadüfən eyni də ola bilər; onlar məntiqi baxımdan yenə iki ayrı meyardır.

Azərbaycan və fars dillərində izahedici nümunələr

Birinci nümunədə öhdəliklə imkan arasındakı fərq görünür. Mənbə cümlə belə qurulur: «İşəgötürən sənədi işçiyə təqdim etməlidir». Mənanı qoruyan farsca variant « کارفرما باید سندرا به کارگر ارائه کند» ola bilər. «تواند سندرا به کارگر ارائه کندکارفرما می» cümləsi də təbii farscadır, lakin «bilmək / edə bilmək» mənası işəgötürənin təqdimat vəzifəsini onun seçə biləcəyi bir hərəkətə çevirir. Problem sözün səslənməsində yox, işəgötürəndən nə tələb olunduğunun dəyişməsindədir. Həqiqi sənəddə daha uyğun farsca termin seçimi mətnin kontekstinə görə dəqiqləşdirilməlidir.

İkinci nümunə tərəflərin yerini yoxlamağa imkan verir: «İşçi işəgötürənə yazılı bildiriş göndərir». «کندکارگر اطلاعیهٔ کتبیرا به کارفرما ارسال می» cümləsində göndərən işçidir. « کارفرما اطلاعیهٔ کتبیرا کندبه کارگر ارسال می» cümləsində isə göndərən işəgötürən olur. Farsca variantların ikisi də aydındır. Bununla belə, ikinci variant mənbədəki göndərənlə alanın yerini dəyişir. Burada «bildiriş» üçün seçilmiş farsca ifadə real sənədin terminoloji həlli kimi yox, tərəflərin rolunu göstərən nümunə kimi işlənir.

Üçüncü nümunədə hərəkətin zaman şərti dəyişir: «Tərəf bildirişi aldıqdan sonra sənədi təqdim edə bilər». Uyğun farsca ifadə «تواند سندرا ارائه کندطرف پس از دریافت اطلاعیه می» şəklində qurula bilər. «تواند سند را ارائه کندطرف پیش از دریافت اطلاعیه می» cümləsindəki «پیش از» qrammatik baxımdan düzgündür, lakin «aldıqdan sonra» məzmununu «almazdan əvvəl»ə çevirir. Sənədi təqdim etmək imkanının hansı hadisədən sonra yarandığı beləliklə iki cümlədə fərqli olur.

Dördüncü nümunə inkara aiddir: «İşçinin razılığı olmadan məlumat açıqlana bilməz». « اطلاعات «اطلاعات بدون رضایت کارگر قابل افشا است» cümləsi qadağanı saxlayır. «بدون رضایت کارگر قابل افشا نیست» ifadəsi isə cümlənin qalan hissəsini qorusa da, son inkardan imtina etdiyi üçün əks məna yaradır. Məna dəqiqliyini qiymətləndirən şəxs təkcə «razılıq» termininin qarşılığına deyil, «mümkün deyil» mənasının cümlə sonunda qalmasına da baxmalıdır.

Beşinci nümunə məhdudlaşdırıcı sözün əhatəsini göstərir: «Yalnız yazılı müraciət əsasında sənədin surəti verilə bilər». «رونوشت سند فقط بر اساس درخواست کتبی قابل ارائه است» cümləsi yazılı müraciəti zəruri şərt kimi təqdim edir. «رونوشت سند بر اساس درخواست کتبی نیز قابل ارائه است» isə yazılı müraciəti mümkün yollardan biri kimi göstərir. «فقط» ilə «نیز» arasındakı fərq cümlənin səslənişini korlamır, lakin müraciətin hüquqi rolunu dəyişir. Bu nümunələr göstərir ki, zahirən çox kiçik bir əvəzlənmə bütün cümlənin ifadə etdiyi qaydanı yenidən qura bilər.

Beş nümunəni birlikdə götürdükdə müxtəlif dəyişikliklərin eyni nəticəyə aparmadığı görünür. Birinci cümlədə hərəkətin məcburi olub-olmaması, ikincidə hərəkəti kimin etməsi, üçüncüdə onun

nə vaxt mümkün olması, dördüncüdə qadağanın mövcudluğu, beşincidə isə şərtin istisna xarakteri dəyişir. Bunları ümumi «söz səhvi» adı altında birləşdirmək tərcüməni düzəldən şəxsə az kömək edər. Hər bir halda əvvəlcə məna əlaqəsinin hansı hissəsinin pozulduğunu göstərmək, yalnız bundan sonra daha münasib farsca ifadəni seçmək mümkündür. Fərqlərin ayrı-ayrı göstərilməsi onların müqayisəsini asanlaşdırır.

Nümunələrin hər birində fərqli söz seçimləri hədəf dildə qrammatik cəhətdən mümkündür. Bu müşahidə heç bir sistemin həqiqətən həmin səhvi etdiyi barədə məlumat deyil. Onun nəzəri nəticəsi budur: hədəf dildə düzgünlük yoxlaması ilə mənbə–hədəf münasibətinin yoxlanması ayrı əməliyyatlardır. İkinci əməliyyat aparılmayanda axıcı cümlənin başqa bir qayda yaratdığını görmək çətinləşə bilər.

Birinci və beşinci nümunə birlikdə oxunanda modal felin düzgün seçilməsinin niyə təkbaşına kifayət etmədiyi də görünür. «Verilə bilər» farscaya uyğun imkan forması ilə keçirilsə belə, «yalnız» sözü düşərsə, imkanın yaranma şərti genişlənir. Əksinə, «yalnız» saxlanıb imkan öhdəliklə əvəz olunsa, bu dəfə hərəkətin hüquqi gücü dəyişir. Beləliklə, cümlənin dəqiqliyi bir sözü düzgün çevirməklə təmin edilmir; bir neçə kiçik vahidin eyni qayda daxilində necə əlaqələndiyinə baxmaq lazımdır. Bu əlaqə xüsusən daha uzun və bir neçə şərti birləşdirən cümlələrdə diqqət tələb edir.

İkinci və üçüncü nümunələr isə cümləni sadələşdirərkən hansı məlumatın itə biləcəyini göstərir. «Bildiriş göndərilir» kimi şəxssiz ifadə, mənbədə göndərən açıq göstərilmişsə, həmin tərəfi görünməz edə bilər. «Sənəd təqdim oluna bilər» ifadəsi də bildirişin alınması şərtini çıxararsa, mənbənin icazə verdiyi anla farsca mətnin bildirdiyi an fərqlənər. Bu cür qısaltmalar bəzən hədəf dili daha hamar göstərir. Onların qəbul edilə bilməsi isə ifadənin neçə sözlə yazılmasından deyil, mənbədəki zəruri məlumatın saxlanıb-saxlanmamasından asılıdır.

Nəzəri təhlilin nəticələri

Kontrastiv nümunələrdən birinci nəticə çıxır: hüquqi cümlənin mənası ən azı üç suala ayrılaraq yoxlana bilər. Hərəkəti kim edir, hərəkət hansı gücə malikdir və hansı şərtlə baş verir? «Təqdim etməlidir» ilə «təqdim edə bilər» arasındakı fərq ikinci suala, işçi ilə işəgötürənin yerinin dəyişməsi birinci suala, bildirişdən əvvəl və ya sonra hərəkət etmək isə üçüncü suala aiddir. Bu suallar sözlük qarşılığından əvvəl cümlənin skeletini görməyə kömək edir.

İkinci nəticə ondan ibarətdir ki, axıcılıqla dəqiqlik arasında məntiqi ziddiyyət yoxdur. Tərcümə həm axıcı, həm də dəqiq ola bilər. Problem axıcılığın dəqiqliyə sübut kimi götürülməsidir. Əslində farsca səslənişin yaxşı olması cümlənin fars dili baxımından uğurlu qurulduğunu göstərir; Azərbaycan dilində verilmiş qaydanın qorunduğunu isə ayrıca qarşılaşdırma göstərməlidir. MQM Council (n.d.) tərəfindən keyfiyyət ölçülərinin ayrılması bu fərqi təsvir etmək üçün münasib terminoloji imkan yaradır.

Üçüncü nəticə nümunələrin tətbiq sərhədinə aiddir. Məqalədə qurulmuş cümlələr səbəb–nəticə münasibətini görünən edir, lakin real hüquqi sənədin çoxmaddəli quruluşunu, ayrıca tərifləri və institusional terminologiyasını əvəz etmir. Deməli, burada təklif olunan oxu üsulu tam hüquqi ekspertiza deyil. O, ilkin tərcüməyə baxarkən nəzərdən qaça bilən məna nöqtələrini sistemləşdirən sadə analitik vasitədir.

Dördüncü nəticə baxışın ardıcıllığına aiddir. Farsca cümlənin əvvəlcə üslubunu cilalamaq oxucunu mənbədən uzaqlaşdıra bilər, çünki hər dəyişiklikdən sonra artıq düzəldilmiş, daha səlis bir hədəf mətn yaranır. Ona görə də əvvəl məna əlaqələrinin yoxlanması, sonra ifadənin rahatlığının təkmilləşdirilməsi tövsiyə olunur. Burada sərt mexaniki tərcümə təklif edilmir: məna qorunduğu müddətdə farsca quruluş rahatlıqla dəyişdirilə bilər. Söhbət həmin dəyişiklik zamanı hüquqi münasibətin yenidən qurulmamasına diqqət yetirməkdən gedir.

Müzakirə və təkliflər

Nəzəri təhlil tərcüməni yoxlamağın oxu ardıcıllığına dair praktiki təklif verir. Əvvəl Azərbaycan dilindəki cümlədən hüquqi münasibətin qısa sxemi çıxarılmalıdır: tərəf, hərəkət, icazə və ya öhdəlik, şərt, inkar və məhdudiyyət. Sonra farsca cümlədə eyni elementlərin hansı sözlərlə ifadə

edildiyi müəyyənləşdirilməlidir. Yalnız bundan sonra farsca üslubun təbiiliyi və terminlərin uyğunluğu ayrıca nəzərdən keçirilə bilər. Bu ardıcıllıq farsca üslubu əhəmiyyətsiz saymır; onun məna yoxlamasının yerini tutmasına imkan vermir.

Məsələn, mənbədə «yalnız yazılı müraciət əsasında» yazılıbsa, yoxlayıcı əvvəlcə yazılı müraciətin məcburi şərt olub-olmadığını müəyyən etməlidir. Daha sonra farsca cümlədə «فقط» sözünün həmin şərtə bağlandığını yoxlamalıdır. Cümlə farsca daha rahat səslənsin deyə sözlərin yeri dəyişdirilə bilər, amma məhdudlaşdırıcının əhatəsi dəyişməməlidir. Eyni üsul «etməlidir» və «edə bilər» fərqinə, eləcə də «əvvəl», «sonra», «olmadan» və «deyil» kimi kiçik vahidlərə tətbiq olunur.

Bu oxu qaydası hüquqi tərcümə tədrisində də yararlı ola bilər. Tələbəyə mənbə cümlə ilə yanaşı iki təbii farsca variant təqdim edildikdə ondan «Hansı variant daha gözəl səslənir?» yox, «Hansı variantda hüquqi münasibət dəyişmir?» sualına cavab vermək istənə bilər. Belə tapşırıq dil biliyi ilə məna təhlilini ayırır. Eyni zamanda nümunələrdən faktiki süni intellekt bacarığı haqqında hökm çıxarılmamalıdır: buna ayrıca mətn seçimi, real sistem çıxışları və müstəqil qiymətləndiricilər tələb olunur.

Yoxlama vərdişini gücləndirmək üçün qısa mətn üzərində tərs istiqamətli sual da verilə bilər: farsca cümləni oxuyan şəxs hansı hərəkətin məcburi, hansının mümkün olduğunu başa düşəcək? Cavab mənbə cümləni oxuyan adamın çıxardığı nəticə ilə tutuşdurulur. Bu üsul avtomatik geri tərcümənin nəticəsinə kor-koranə inanmaq demək deyil. Məqsəd oxucunun qarşısına çıxan iki müxtəlif qaydanı ayrıca ifadə etməkdir. Məsələn, «sənədi verə bilər» və «sənədi verməlidir» cümlələrinin eyni vəziyyətdə tərəfdən eyni davranışı tələb etmədiyi dərhal görünür.

Bu metodun təlim və redaktə üçün uyğunlaşdırılmasının bir yolu, hər nümunəni iki ayrı rəng və ya işarə ilə yoxlamaqdır: mənbədə normativ qüvvə bildirən hissə və farscada onun qarşılığı; mənbədə tərəf bildirən hissə və farscada həmin tərəf. Bu sadə işarələmə təhlilin nəticəsini görünən edir. Yenə də yoxlayıcının hüquqi anlayışı bilməsi vacibdir; işarələmə özü termin seçimini həll etmir. Xüsusən mənbədəki «bilər» sözünün fiziki imkan, hüquq və ya səlahiyyət bildirdiyi kontekstə baxılmadan müəyyən olunmursa, hədəf cümlənin uyğunluğu barədə tez qərar vermək olmaz.

Təklif edilən yanaşmanın bir başqa tərəfi qeyri-müəyyənliyi saxlamasıdır. Mənbə cümlə birdən çox oxunuşa açıqdırsa, tərcümə onu səbəbsiz olaraq tək mənaya endirməməlidir. Bəzən tərcüməçi aidiyyəti sənədin başqa bəndlərini yoxlayaraq mənanı dəqiqləşdirə bilər; bəzən isə əlavə hüquqi izah tələb olunur. Burada seçilmiş qısa nümunələr belə real qeyri-müəyyənliyi tam əks etdirmir. Bu səbəbdən məqalənin təklifi «hər cümlə bir düstura salına bilər» kimi yox, tərcüməçinin hansı münasibətləri sorğulamalı olduğunu göstərən məhdud bir oxu vasitəsi kimi başa düşülməlidir.

Bu yanaşma süni intellektin istifadəsinə dair qəti mənfi nəticə çıxarmır. Süni intellekt ilkin farsca variantı hazırlamaqda, alternativ ifadələr təklif etməkdə və təkrar olunan hissələri göstərməkdə kömək edə bilər. Tərcümənin məna baxımından yoxlanması isə alətin təqdim etdiyi son cümləni mənbə cümlə ilə tutuşdurmağı tələb edir. ISO 5060:2024-ün insan və maşın mənşəli məhsulları xəta növləri əsasında qiymətləndirməyi mümkün sayması da məhsulun mənşəyindən asılı olmayaraq konkret fərqlərin görünməsinin əhəmiyyətini göstərir. Məqalənin təklifi alətlər arasında seçim yox, belə fərqləri daha asan ifadə edən bir oxu ardıcıllığıdır (International Organization for Standardization, 2024).

Mövzunun sonrakı tədqiqi üçün ən sadə empirik sual da müəyyənləşir: peşəkar yoxlayıcıya yalnız axıcı farsca mətn göstərildikdə və hər iki dil yanaşı təqdim edildikdə aşkarlanan məna səhvləri fərqlənirmi? Bu sual hazırkı yazıda cavablandırılmır. Ona cavab vermək üçün əvvəlcədən müəyyən edilmiş sənəd toplusu, real model çıxışları, qiymətləndirmə meyarları və iştirakçıların fəaliyyəti haqqında məlumat lazımdır. Nəzəri yazının dəyəri həmin sınağın nəticəsini əvvəlcədən söyləməsində deyil, yoxlanılması mümkün olan fərziyyəni və nəzərdən qaçan məna nöqtələrini aydın adlandırmasındadır.

Nəticə

Süni intellektin hazırladığı və ya onun köməyi ilə redaktə edilmiş hüquqi tərcüməni yalnız hədəf dilin təbiiliyinə əsasən qiymətləndirmək yetərli deyil. Azərbaycan dilindən fars dilinə tərcümədə eyni dərəcədə axıcı görünən iki cümlə fərqli hüquqi münasibətlər ifadə edə bilər. Öhdəlik imkan kimi, bildirişi göndərən tərəf qəbul edən tərəf kimi, hərəkətin başlanma şərti isə əks zaman ardıcıllığı ilə göstərilə bilər. İnkar və «yalnız» kimi məhdudlaşdırıcı vahidlərin itməsi də mətnin ümumi oxunaqlığını azaltmadan məzmunu dəyişə bilər.

Məqalənin töhfəsi bu fərqi beş qısa, izah üçün qurulmuş Azərbaycan–fars nümunəsi ilə göstərməsi və ilkin tərcüməni yoxlamaq üçün tərəf, hərəkət, normativ qüvvə, şərt, inkar və əhatə ardıcıllığını təklif etməsidir. Bu, geniş risk idarəçiliyi modeli deyil, çıxış cümləsinin mənbə ilə müqayisəsi üçün məhdud bir oxu üsuludur. Nümunələr empirik model sınağı sayılmır; səhvlərin tezliyi barədə nəticə vermir. Gələcəkdə bu sual real mətnlər və model çıxışları üzərində ayrıca sınaqdan keçirilə bilər.

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La communication en tant que phénomène de discours et les différents composants de la communication

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La linguistique est la discipline s'intéressant à l'étude du langage au niveau de l'écrit, oral, les aspects syntaxiques et grammaticaux. Elle est une science humaine basée sur : l'observation, l'expérience et le résultat; ce résultat n'est pas exact, n'est pas figé mais évolutif. Elle se distingue de la grammaire, dans la mesure où elle n'est pas prescriptive(ne donne pas des normes) mais descriptive (elle décrit l'état de l'homme) Les écoles leurs principes et démarches ? La langue de 18e siecle et de 19e siecle ? Au 18eme siècle : séparation des pouvoirs et d'églises = liberté d'esprit, linguistique est une séance Au 19eme siècle : un système colonial, découverte de plusieurs civilisations et continents Comparaisons entre les écoles linguistiques ? Quand la linguistique est apparait ? La linguistique est apparait avant Platon, avec l'apparition de l'écriture avec les phéniciens à cause de la diversité et selon le besoin de la communication surtout dans le domaine de la commerce. 1ere écriture était un découpage par des unité sonore (transcription phonétique) chaque son correspond à un symbole (écriture symbolique) développée par la suite par les grec qui ont ajouté les voyelles Définition de la linguistique : Introduction : « la linguistique est un savoir très ancien(un acquis, un apprentissage : lire et écrire depuis l'antiquité), mais c'est une science très jeune (théorie basée sur l'observation, l'expérience et resultat) ». Selon le point de vue ou se place la linguistique est née vers le 5eme siècle avant jésus ou 19 eme siècle avec grand comparatif, ou en 1916 avec Ferdinand de Saussure. Les réflexions sur les langues ne sont pas récentes, depuis l'antiquité elles ont en effet suscité l'invention des écritures et plusieurs analyses des structures des langues : les hindous, les phéniciens, les grec et les arabes ont jeté les premières bases d'une analyse linguistique, toutefois la linguistique autant que science autonome ne s'est constitués qu'au cours du 19 eme siècle. Le Moyen Age : Le moyen âge a connu de grandes réformes de l'orthographe activés par l'invention de l'imprimerie. Ceci va stimuler jusqu'au 16 eme siècle l'étude de la phonétique (pas de blanc, et création de la ponctuation). C'est l'âge grâce auquel et grâce au contacte avec d'autres langues. C'est l'âge des premières comparaisons entre les langues, et la formation des premières classifications des langues .En s'appuyant essentiellement sur une approche historique. L'historisme est une théorie idéologique explicative qui tente d'analyser et d'expliquer tout les phénomènes linguistiques mais aussi politiques sociologiques psychologique …Par référence à l'histoire. Etudier une langue c'est se référer obligatoirement à l'histoire, c'est tenter de trouver sa forme primitif (étymologie) On veut lorsqu'on étudie le français se référer en latin, on décrivait le français selon les structures du latin, or le latin est une langue casuelle : « une langue a cas elle a la particularité de voir la fin des mots changés selon leurs fonctions ».Alors que le français est une langue à réaction « c'est-à-dire c'est l'ordre syntaxique des mots qui est important et qui indique la fonction des mots. » (la langue Française n'est pas une langue à cas) Les années qui ont suivit la renaissance ont servit à collecter des données pour la linguistique comparative tel que : Dictionnaires, texte, etc.… La linguistique du 18 eme et du 19 eme siècle : L'approche historique a dominé jusqu'à le sanscrit (d'origine indien) par le contacte de l'Europe et de l'inde, la réflexion sur les langues entre dans l'âge de

l'approche comparée. A la suite du courant philologique qui étudie les textes écrits à des fins de descriptions historique le langage devient un objet d'observation pour lui-même.
Chez les grammairiens comparatistes au 19 eme siècle les grammairiens ont essayés d'expliquer les langues en rétablissant des comparaisons entre les langues. Louis Ferdinand de Saussure lui-même initie a cette démarche (comparative) va se révolter contre la conception historique des faits linguistiques, dans son ouvrage « cours de la linguistique général » il va souligner l'aspect structural de la langue. La langue selon lui est un système dont le signe linguistique est l'élément fondamental. I. De Saussure et le structuralisme : Louis Ferdinand de Saussure de sa jeunesse à l'école des néogrammairiens (grammaire comparatiste) a fait ses premiers recherches linguistiques sur l'indo européen il a essayé de trouver le système phonétique de l'indo-européen dans sa mémoire intitulé « mémoire sur le système vocalique en indo européen » sur le système vocalique en indo européen. Saussure a utilisé un raisonnement structural a propos d'une étude historique cet ouvrage constitue le lien entre l'ancien théorie grammaticale historiciste et le nouveau raisonnement structural Le raisonnement structural a été développé dans l'ouvrage « cours de linguistique générale » la base de linguistique moderne dans laquelle Saussure va se révolter contre la conception historique des faits linguistiques et souligner l'aspect structural de la langue Saussure a conçu plusieurs concepts grâce auquel le structuralisme va naitre 1. La notion de signe linguistique : Le signe linguistique selon Saussure est une entité double qui annonce un signifiant (face acoustique) et un signifié (face conceptuelle) L'association entre le signifiant et signifié est arbitraire c a d : que le signifiant n'a aucune attache réelle de la réalité par rapport au signifié, mais conventionnelle Le signifiant est imposé par la communauté linguistique il ne dépend pas de libre choix des individus pour cela qu'il est conventionnelle La langue selon Saussure est un système de signes linguistiques qui entretiennent entre eux des relations d'opposition et de complémentarité sur deux axes : L'axe paradigmatique : (l'opposition, les neufs parties de discours) L'axe syntagmatique : (complémentarité) La langue est découpée en unité segmentale, discret car le quantiniume est linéaire (grammaire= gramma= lettre) 2. La notion de la linéarité de signifiant : (orale) C'est la deuxième loi dégagée par Saussure le signifiant linguistique contrairement aux autre signifiant se démoule dans une dimension spatio-temporel il se présente tout à l'oral qu'à l'écrit par un choix d'éléments successifs, à l'oral il s'agit de la succession des sons et à l'écrit il s'agit de la succession des lettres cette mot fondamentale de linéarité débauche sur la notion fondamentale d'articulation : la 1 et la 2eme articulation (grammaire lexique) 3. La langue et la parole : Saussure fait la dichotomie (opposition binaire) entre la langue et la parole :
La langue est un fait social conventionnel, abstrait, collectif alors que la parole est un fait réel concret individuel et accidentel (dépend de la situation) grâce à cette dichotomie plusieurs branches de linguistique vont naitre : 4. Etudes diachronique/synchronique de Saussure : Saussure introduit une dichotomie fondamentale entre des faits linguistiques, le linguiste selon le cas peut opter pour une étude diachronique de la langue en s'intéressant de son évolution dans le temps il va étudier les facteurs extérieurs et intérieurs qui provoquent cette évolution (les guerres la diversité des cultures, (s= ^- hôpital= hospital) Ces linguistes choisiront d'étudier l'aspect synchronique de la langue c a d : ils s'intéresseront à un état stable de la langue par exemple : étudier le français contemporain 5. La valeur de signe linguistique : Langue= système=loi clôt et indépendant Selon Saussure la langue constitue un élément indépendant et clôt (on n'est pas besoin de l'histoire de religion de l'histoire de l'idiologie, la sociologie, pour expliquer c'est quoi la langue il suffit à luimême) elle est constituée de signe chaque signe à une valeur à l'intérieur de système II. COMMANTAIRE D'UN TEXTE LINGUISTIQUE Introduction : Préciser la thématique Plan + questions Développement : Dégager les idées principales Il faut se documenter Conclusion : Donner une synthèse : Texte de Saussure fait à classe Le passage nous présente une évolution dans la réflexion linguistique dans deux époques différentes depuis l'antiquité jusqu'à Saussure on va expliquer deux parties d'une part une relative d'étude avant Saussure et d'autre part une

relative avec Saussure distinguent les transformations qui sont ajoutés à la démarche linguistique et précise les caractéristiques de chaque époques 1ere partie : avant Saussure La recherche linguistique avant Saussure était fondé seulement sur des théories imposés de façons aléatoire sans aucune démarche analytique et scientifique on rend compte seulement de la langue écrite cette étude s'est limité sur la segmentation des unités grammaticales et s'est focalisée sur les parties de discours d'une manière plus ou moins globale, il s'est attaché à la comparaison avec les autres langues la grammaire c'est le travail sur la lettre (gammaire= gramma = lettre) ; n'est pas récente Le travail sur la notion de la structure n'est pas récent depuis l'antiquité la linguistique c'est un savoir ancien et c'est une science moderne même de manière inexacte et aléatoire pas scientifique. En se fondant sur la langue écrite.

Rapportée à l'espace global de la communication, notre exemple aura voulu montrer que la dynamique de la communication (qui implique à la fois émergence, fonctionnalisation et distanciation des codes – de tous les codes, linguistiques ou non – dans le procès, toujours contingent, de mise en signification des énoncés dans les échanges langagiers) induit le renouvellement des codes et leur multiplication. Il suggère aussi que la variation naît non pas d'un 'raté' communicationnel qu'il s'agit de résorber mais comme l'adjonction d'un surplus de signification (une mise en signification supplémentaire) qu'il s'agit d'introduire et de négocier dans l'interaction. L'éventualité d'un raté n'est évidemment pas exclue car il s'agit aussi d'un phénomène normal. Mais le raté signifie, il est à la fois disfonctionnel et fonctionnalisé : par sa contextualisation et son incidence même, la matérialité du raté s'inscrit de facto dans le 'répertoire non-fini' des actualisations possibles. A travers sa mémorisation la différenciation ainsi constituée peut se développer en tant que norme puis, le cas échéant, en souscrivant aux contraintes structurales, cognitives et sociales, s'introduire et éventuellement se cristalliser dans la langue aux différents niveaux que sa nature particulière lui permet d'atteindre : sémantique, lexical, phonétique, etc. A partir de là on retiendra que la mise en contact continuelle des codes et la génération de la variation est la donnée normale de la communication, ce qui a pour corollaire que, sauf cas particulier, la situation canonique pour l'étude de la dynamique des langues et du langage ne saurait se définir dans un cadre de monolinguisme qui n'est qu'un cas limite (un cas d'école) parmi les situations de communication. Dans le même temps, on retient que la notion de 'code' telle que je l'ai utilisée par licence d'écriture, a besoin d'être éclaircie et problématisée: elle renvoie à une stabilité qui semblerait aller de soi, dotée d'une homogénéité suffisante pour qu'on puisse en faire une description ; or cela pose problème car cette représentation homogène est un construit. Le fait qu'elle semble aller de soi alors que les phénomènes saisis dans leurs contextes attestent une hétérogénéité et une variabilité dont la nécessité et la fonctionnalité sont constitutives 'du linguistique' lui-même est un problème de dynamique et d'émergence de formes qu'il importe de traiter. Nous avons probablement touché à l'une des dimensions premières, actives dans la dynamique du langage. Transformation des formes linguistiques et normes langagières, élaboration des styles : autant de dynamiques qui mettent en jeu des langues, des codes et les règles de leurs constructions. Il devient alors intéressant de croiser cette problématique avec celle initiée par Fr. Gadet qui pose aussi que le répertoire est une notion non opérationnelle qui « risque de dissimuler la créativité du locuteur, constamment renouvelée et ne s'appuyant pas seulement sur des ressources répertoriées et listables » (2006 : 2), tandis que le style est une ressource pour l'usager. De fait, s'intéressant à la variation et au style, mais d'une façon qui n'est ni celle d'un sociolinguiste variationniste ni celle d'un 'stylisticien', elle oriente la recherche vers la « [mise] à jour [des] pratiques localement saillantes à travers lesquelles les usagers catégorisent le langage, les autres usagers, le monde » (2004 : 110) et on retrouve dans son approche la même tension dans la recherche d'explication « autour de l'idée que le discours se module au fur et à mesure qu'il s'accomplit, en tant que co-construction des participants (locuteur et audience) » (2004 : 106). Dans la

perspective qu'elle brosse le style est à la fois différenciation, écart et norme, contrainte. C'est la manifestation de l'individualité dans un jeu de rôles, un écart maîtrisé par rapport aux règles du groupe et la manifestation de la force collective dans la nécessaire prise en compte de cette dynamique de recomposition qu'implique tout écart. Elle ouvre alors le débat en posant la question : « Pourquoi y a-t-il de la variation dans les langues ; et pourquoi y a-t-il du style ? » (2006 : 4). Pour y répondre, elle abandonne le pré carré des linguistes pour celui des sociologues interactionnistes (Goffman 1964, 1981) desquels elle retient la pertinence de l'intrication de trois phénomènes donnés pour fondamentaux qu'elle rappelle : ritualisation (les distinctions doivent être suffisamment ritualisées, ou conventionnalisées, pour apparaître pertinentes pour l'autre) ; cadre de participation (tout ce qui concerne les relations entre les protagonistes et la situation) ; enchâssement (nous parlons constamment avec les paroles des autres ; cf. l'interprétation occidentale de la polyphonie de Bakhtine). Dans le même temps la question de la construction de l'homogène est posée30 : cela va se faire « à travers l'intervention d'un certain nombre de processus idéologiques de la part des locuteurs tels que gommage 31, ré-analyse, réallocation de variantes, iconisation32» (Gadet 2006 : 5). La dimension de la variabilité ainsi cernée est fondatrice dans la préhension et la compréhension de ce qui caractérise, de façon essentielle 'le linguistique'. Cela ne conduit pas à l'abolition de la notion de langue mais, par la problématisation qu'elle en fait, Fr. Gadet permet de la restructurer, de la démythifier à travers la reconnaissance des jeux, stratégies, élaborations et autres dynamiques qui, dans un espace anthropologique à redéfinir, lui donne sens en tant qu'objet construit / constructible et non plus en tant que cadre transcendant.

Dans l'approche communicative, la compétence est défi nie comme la capacité à utiliser un langage approprié dans des situations et des dispositifs de communication variés (Bachman, 1990 :16). Il distingue « la compétence langagière, organisatrice et pragmatique […] de la compétence stratégique consistant à évaluer, planifi er et exécuter (la maîtrise de la langue doit être transformée en acte) » (cité par Figueras, 2007 : 20). En fait, cette défi nition est à mettre en perspective avec d'autres défi nitions.

La notion de compétence en linguistique apparaît chez Chomsky qui la distingue de la performance – la performance étant la manifestation de la compétence. Cette notion va être utilisée et enrichie par D. Hymes pour qui une compétence de communication est à la fois d'ordre linguistique (Chomsky) et d'ordre socioculturel, ouvrant ici un nouveau paradigme pour l'enseignement des langues. Comme l'écrit C. Springer : « La didactique des langues ne peut pas se contenter d'une approche purement linguistique de la compétence » (2000 : 69). En 1983, P. Charaudeau propose trois composantes : linguistique, situationnelle, et discursive. Canale et Swain (1980) en distinguent quatre : grammaticale, sociolinguistique, discursive etstratégique. En reprenant cette évolution, Springer dessine une « marguerite » de la compétence de communication comprenant les aspects suivants :

La marguerite de la compétence de communication (C. Springer, 1999)

Conversationnelle
Discursive
Stratégique
Linguistique
Sociolinguistique
Socioculturelle

La compétence de communication ne peut donc se réduire à des savoirs (connaissances linguistiques) ou des savoir-faire (maîtrise fonctionnelle). L'approche communicative mise en place dans les années 1980 en France ne prend pas encore en compte toute la complexité du concept. Finalement ce sont les travaux du Conseil de l'Europe et la perspective actionnelle du

Cadre européen commun de référence pour les langues qui vont modéliser la compétence de communication autour de trois composantes : linguistique, sociolinguistique, pragmatique.
La composante linguistique est celle « qui a trait aux savoirs et savoir-faire relatifs au lexique, à la phonétique, à la syntaxe et aux autres dimensions du système d'une langue, pris en tant que tel, indépendamment de la valeur sociolinguistique de ses variations et des fonctions pragmatiques de ses réalisations » (CECRL, 2001 : 17).
La compétence sociolinguistique « renvoie aux paramètres socioculturels de l'utilisation de la langue. Sensible aux normes sociales (règles d'adresse et de politesse, régulation des rapports entre générations, sexes, statuts, groupes sociaux, codification par le langage de nombre de rituels fondamentaux dans le fonctionnement d'une communauté), la composante sociolinguistique aff ecte fortement toute communication langagière entre représentants de cultures diff érentes, même si c'est souvent à l'insu des participants eux-mêmes » (CECRL, 2001 : 18). La compétence pragmatique recouvre « l'utilisation fonctionnelle des ressources de la langue (réalisation de fonctions langagières, d'actes de parole) en s'appuyant sur des scénarios ou des scripts d'échanges interactionnels. Elle renvoie également à la maîtrise du discours, à sa cohésion et à sa cohérence,
au repérage des types et genres textuels, des eff ets d'ironie, de parodie […] » (CECRL, 2001 : 18).
Cette compétence de communication dans la perspective actionnelle est à replacer dans un ensemble plus large de compétences générales reposant sur « des savoirs, des savoir-faire, des savoir-être et des savoir-apprendre »
L'ensemble des connaissances, des habiletés et des dispositions qui permettent d'agir. Ne sont pas propres à la langue mais sont celles auxquelles on fait appel pour des activités de toutes sortes, y compris langagières
Composantes :– savoirs,– savoir-faire,– savoir-être,– savoir-apprendre
> Compétence à communiquer langagièrement. Mise en œuvre des compétences dont on dispose dans des contextes et des conditions variées et en se pliant à diff érentes contraintes afi n de réaliser des activités langagières (production, compréhension, interaction et médiation) permettant de traiter des textes […] dans des domaines (personnel, public, professionnel, éducatif) en mobilisant des stratégies qui paraissent le mieux convenir à l'accomplissement de tâches à eff ectuer
Composantes :– linguistique– sociolinguistique– pragmatique
On remarque que le CECRL utilise le terme de compétences de manière générique, intégrant les connaissances.
-Le terme «communication » a été dérivé du latin « communicare » cela signifie « commun ».
Ainsi « communiquer » signifie « faire commun » ou « faire connaître » ou « partager ». -La définition de la communication est « tout acte par lequel une personne donne à ou reçoit d'une autre personne des informations sur ses besoins, ses désirs, ses perceptions, ses connaissances ou ses états affectifs ». -Elle s'agit d'un processus de transmission d'informations ou de données, d'idées, de pensées, de sentiments, d'émotions par la parole, l'écriture, les gestes, les mimiques, les yeux et même les signaux non verbaux. En d'autres termes, la communication est un processus d'établissement de contacts et de développement de relations entre des personnes. Les éléments de la communication La communication se base sur 6 composants : un émetteur, un récepteur, un contexte, un message, un canal et un feedback.
L'émetteur ou destinateur : Celui qui transmet le message « oralement ou par écrit », il peut s'agir d'un individu ou d'un groupe « firme, entreprise, système ». Le récepteur ou destinataire : Celui qui reçoit le message, ce peut être un individu, un groupe, une machine, etc.
Le contexte : Toute communication se déroule dans un contexte. Cela a un impact sur tout ce que nous disons et sur la manière dont nous le disons. Elle comporte au moins quatre aspects indépendants et interactifs : la culturelle (modes de vie, valeurs), la physique (environnement

tangible ou concret ; par exemple, on ne parle pas de la même manière dans une salle de réunion ou une cafétéria), le socio-physiologique (le caractère formel ou informel de la circonstance, les relations de statut, etc.) et le temporel.
Le message : C'est l'information transmise au cours d'une communication.
Le canal : C'est le moyen technique utilisé par l'émetteur pour assurer l'acheminement de son message vers le destinataire (face à face, téléphone, courrier…).
Le feed-back : Ce terme peut être traduit « rétroaction ». Le feed-back est tout commentaire réponse, réaction ou information donnée par le destinataire d'un message à l'émetteur. Le feedback est essentiel à une communication efficace car il aide l'émetteur à vérifier que son message a été compris et à modifier sa stratégie de communication si nécessaire. Le feedback est crucial dans la
communication bidirectionnelle pour renforcer les liens de confiance et les relations entre l'émetteur et le destinataire et également pour garantir que les deux parties sont sur la même longueur d'onde et peuvent éviter les malentendus ou la confusion. Le malentendu est essentiellement le contraire de la compréhension. En cas de malentendu, le destinateur et le destinataire d'un message se comprennent mal ou ne se comprennent pas du tout.
Un bon feed-back doit être : -Spécifique plutôt que général -Impersonnel (les commentaires doivent être liés au travail, le récepteur ne doit critiquer personne). -Au bon moment (il doit commencer lorsqu'il est réellement nécessaire ou lorsque le destinataire le recherche activement).
Communication -Orienté vers l'objectif de l'émetteur (les commentaires doivent se concentrer uniquement sur les domaines, actions et comportements sur lesquels le destinataire exerce un contrôle personnel). - Compris par le destinataire (utilisez des compétences de questionnement et d'écoute efficaces pour vous assurer que vos commentaires peuvent être classés comme une communication significative).

Emetteur	Message	Récepteur
Codage/décodage	Feed-Back	Décodage/ codage

Représentation simplifier de la communication.
Vers 1960, A.D. Chandler a donné la première définition de la stratégie : « La stratégie est le processus d'identification des buts et des objectifs fondamentaux à long terme d'une organisation,suivi de la sélection des modes d'action et de l'allocation des ressources qui permettront d'atteindre ces objectifs et buts ».

Les types de la communication

La communication verbale : La communication verbale est un type de communication dans lequel nous utilisons les mots parlés et écrits pour transmettre notre message et nos informations à l'autre personne. La communication verbale est l'expression d'informations à travers un langage composé de mots et de grammaire.
La communication non-verbale : En général, le langage corporel fait référence à un ou plusieurs comportements non verbaux (par exemple, la posture, le regard, le toucher, l'expression faciale) qui signalent vraisemblablement quelque chose sur les traits de personnalité, les relations, les motivations, les états momentanés et, finalement, leur véracité. On pensait souvent que le langage
corporel des gens, bien qu'indirect, transmettait plus de vérité à leur sujet que leurs paroles.
La communication para-verbale : La communication para-verbale est également connue sous le nom de langage vocal. Il s'agit d'un niveau de communication plus profond et les informations codées sont envoyées à travers la prosodie et les éléments vocaux accompagnant le mot et la parole.

Les signaux para-verbaux sont des signaux vocaux qui peuvent être détectés en interne lors du comportement vocal et font référence aux messages que nous transmettons à travers la hauteur, le rythme et le ton de notre voix.

La communication interpersonnelle : La communication interpersonnelle est l'interaction verbale et non verbale entre deux (ou parfois plus de deux) personnes interdépendantes. Bien que de nature largement dyadique (à deux), la communication interpersonnelle est souvent étendue pour inclure de petits groupes intimes tels que la famille.

Elle est également la communication qui a lieu entre des personnes qui sont d'une manière ou d'une autre « connectées ». Non seulement les individus sont simplement « connectés », mais ils sont également interdépendants : ce que fait une personne a un impact sur l'autre. Les actes d'une personne ont des conséquences sur l'autre.

La communication de groupe : La communication de groupe est la communication entre un petit groupe de personnes partageant un objectif commun, ressentant un sentiment d'appartenance au groupe et exerçant une influence les unes sur les autres. La communication de masse : La communication de masse consiste à envoyer un seul message à un groupe. Cela nous permet de communiquer notre message à un grand nombre de personnes, mais nous sommes limités dans notre capacité à adapter notre message à des publics, des groupes ou des individus spécifiques.

La communication externe : La communication externe consiste à amener les informations de l'extérieur de l'organisation. Dans la communication externe les informations circulent dans l'environnement extérieur de l'organisation. Les entreprises échangent constamment les messages avec leurs clients, fournisseurs, distributeurs, concurrents, investisseurs, journalistes, représentants des structures étatiques et autres.

La communication interne : La communication interne est un échange d'informations et d'idées au sein de l'organisation. Les informations de la communication interne se transmettent de haut en bas, horizontalement et en diagonale dans la structure organisationnelle. Une communication efficace ne se limite pas à l'échange d'informations. Une communication efficace est la capacité d'avoir une conversation avec une autre personne d'une manière engageante, ciblée, cohérente et offrant de la valeur. En plus d'être capable de transmettre clairement un message, vous devez également écouter de manière à saisir tout le sens de ce qui est dit et à faire en sorte que l'autre personne se sente entendue et comprise.

Communiquer efficacement implique deux personnes ou plus qui peuvent exprimer clairement leur intention et comprendre l'objet ou le but de la conversation, tout en permettant à chaque personne de faire passer son message.

Les facteurs influencent l'efficacité du message

Les facteurs para verbaux

*Le volume : Le volume de notre voix doit être suffisamment fort pour se faire entendre par l'ensemble des auditeurs et assurer une écoute agréable de notre message.

*Le rythme : (débit de paroles) lors d'une présentation publique, l'auditeur doit saisir les mots sans avoir besoin de les réentendre.

De ce fait, parler trop vite nuit à la compréhension de notre message. Par ailleurs, un débit trop important est souvent une manière de traduire le trac que nous ressentons quand nous prenons la parole en public et risque de nous faire perdre le fil de nos idées.

Réduire la vitesse de nos paroles correspond à une amélioration de la compréhension de notre message, mais aussi à la gestion du stress inhérent à la situation.

*Le ton : Le ton sur lequel une phrase est énoncée détermine fortement le sens qui lui est attribué (affirmatif, interrogatif, agressif, autoritaire par exemple). L'intonation utilisée doit donc correspondre à la signification que nous souhaitons donner à nos paroles.

*L'articulation et la prononciation : La manière dont nous énonçons les mots est également à prendre en considération. Pour se faire comprendre, il s'agit d'articuler distinctement, sans

exagérer, les sons qui composent les mots. Quant à la prononciation, elle varie dans l'espace et dans le temps. Elle contribue notamment aux accents régionaux. A cet égard, avoir un accent particulier n'est pas une tare. Nous devons toutefois être attentifs à l'impact de notre prononciation sur la compréhension des mots, surtout si notre auditoire est composé de personnes issues d'autres régions.

Les facteurs non verbaux

*Le regard : Bien plus que regarder notre public, il s'agit d'établir avec lui un contact visuel. Il indique l'intérêt que nous portons à nos auditeurs, capte et maintien leur attention. Ce contact permet également de contrôler les réactions du public face à nos propos.

*Les silences : Quand nous prenons la parole en public, nous avons souvent tendance à ne pas laisser s'exprimer les silences. Soit parce que nous voulons dire trop de choses en trop peu de temps, soit parce que nous voulons combler ce vide qui nous fait peur.

Or, s'ils sont respectés, ces silences ont souvent une fonction positive. Avant de prendre la parole, le silence permet de solliciter l'attention du public. En cours de présentation, il peut donner le temps nécessaire aux auditeurs pour assimiler ou pour réfléchir à une information importante que vous venez de leur donner.

Les gestes : Nos gestes expriment toujours quelque chose. Ils peuvent traduire ce que nous essayons de cacher : notre nervosité, notre gêne par exemple en manipulant un stylo ou des lunettes, en se pinçant le menton. Il s'agit là de gestes parasites qui viennent perturber notre présentation ; ils attirent l'attention de notre auditoire au détriment de son écoute et peuvent vite devenir agaçants.

Eviter de se figer en s'appuyant sur la table, en mettant les mains en poche ou en croisant les bras, cela renforcerait une attitude non naturelle, rigide portant préjudice à la transmission, et de ce fait à la compréhension de notre message. A l'inverse, les gestes peuvent renforcer, appuyer, notre message verbal ; ils rythment, illustrent, s'accordent avec notre discours et animent la présentation.

Les mouvements : Le fait de bouger, de se déplacer donne un certain dynamisme à la présentation. Toutefois, mieux vaut ne pas être constamment en mouvement ou faire des mouvements trop prévisibles. Les premiers risquent de monopoliser l'attention des auditeurs, alors que les seconds deviennent vite une source de monotonie et d'ennui pour l'auditoire. A l'inverse, éviter de rester statique, ce qui peut donner l'impression d'un orateur craintif ou distant.

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Technical Sciences

The Impact of the Skin Effect on the Economic Costs of Power Transmission Systems

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Annotation. The skin effect is a phenomenon in which an alternating electric current is not distributed uniformly throughout a conductor but instead flows primarily within its surface layers. The skin effect is significant in electrical engineering because it increases resistance in high-frequency power transmission lines, leading to energy losses. This paper examines a practical example and calculates the skin depth for a copper conductor at a specific temperature. It also compares alternating current (AC) and direct current (DC) power transmission systems, evaluating the impact of the skin effect on energy losses and economic costs. Based on the practical example, energy losses in transmission lines are calculated, and the potential annual economic benefit of using a DC line instead of an AC line is demonstrated.

Keywords: Power Transmission Systems, Skin Effect, Economy

Introduction

The skin effect is a phenomenon in which an alternating electric current is not distributed uniformly throughout a conductor, but instead flows primarily within its surface layers [1]. The higher the frequency of the alternating current, the more the electrons are pushed from the central part of the conductor toward its surface [2]. This effect does not occur with direct current, as direct current is distributed uniformly across the entire cross-section of the conductor [3]. Comparing high-voltage alternating current (AC) transmission with high-voltage direct current (DC) transmission systems reveals the impact of the skin effect on both energy losses and economic costs [4].

Main Part

In an alternating current (AC) system, the skin effect causes current to become more concentrated near the surface of the conductor [5]. Consequently, resistance and electrical losses increase. In a steady-state direct current (DC) system, the current is distributed almost uniformly across the conductor's cross-section; therefore, the skin effect has practically no impact [6]. The relationship between the skin effect and current frequency can be stated as follows: the higher the frequency, the more pronounced the skin effect (Table 1).

Table 1

Current Frequency	Skin Effect
0 Hz – Direct current, steady-state	Virtually non-existent
50 Hz – AC power grid	Present; depends on the conductor material, diameter, and other conditions

The skin effect depends on the conductor's material, its diameter, and other conditions [7]. Alternating current generates an alternating magnetic field, which influences the distribution of current within the conductor [8]. As the frequency increases, the current becomes more concentrated in the outer layer of the conductor [9]. The relationship between the skin effect and the conductor's diameter can be stated as follows: for a given material and frequency, the larger the conductor's diameter, the more pronounced the skin effect becomes [10]. With a smaller diameter, the current distribution across the cross-section is more uniform [11]. In the case of a large diameter, the current density toward the center of the conductor can decrease significantly, as the current flows primarily through the outer layer [12]. It is worth noting that a conductor with a larger diameter typically has a lower resistance to direct current (DC). In an alternating current (AC) system, the skin effect is influenced by the conductor material (e.g., copper, aluminum, etc.) and its corresponding electrical resistivity [13]. To estimate the depth of the skin effect, the classical formula (1) is used, denoted by δ:

$$\delta = \sqrt{(\rho / (\pi \cdot f \cdot \mu_o \cdot \mu_r))} \quad (1)$$

where: δ is the skin effect depth (m); ρ is the electrical resistivity of the conductor (for copper at a temperature of 20°C, $\rho \approx 1.72 \times 10^{-8}$ Ω·m); π is 3.14; f is the current frequency (in this case, 50 Hz); μ_o is the magnetic permeability of a vacuum ($4\pi \times 10^{-7}$ H/m) [14]; and μ_r is the relative magnetic permeability of the material (for copper, $\mu_r \approx 1$) [15].

Substituting these values into formula (1) yields the skin effect depth in meters:

$$\delta = \sqrt{((1.72 \times 10^{-8}) / (\pi \times 50 \times (4 \times 3.14 \times 10^{-7}) \times 1))} \approx 0.00933 \text{ meters, or } 9.33 \text{ mm.}$$

Thus, for a copper conductor at a frequency of 50 Hz, the skin depth is approximately 9.33 mm. It should be noted that as the frequency increases, the skin effect becomes more pronounced [16]; similarly, as the conductor diameter increases, the impact of the skin effect generally becomes more noticeable [17]. Conversely, in steady-state direct current (DC) systems, the skin effect is practically non-existent. In a direct current (DC) transmission line, the established current is constant; therefore, it lacks the fixed frequency characteristic of conventional alternating current (AC)-such as the 50 Hz frequency found in AC systems [18]. However, AC components and harmonics of varying frequencies can arise within DC converters [19]. It is precisely these components that can give rise to the skin effect. While the actual resistance and losses of a conductor must be evaluated at the 50 Hz AC frequency, in the case of DC, it is also necessary to assess the impact of transient processes and harmonic components [20].

The skin effect influences both power losses and economic costs in DC and AC systems. Using a practical example, we will compare the losses in the conductors of 100 km-long AC and DC transmission lines and determine the potential annual economic impact [21]. The initial data are presented in a table (Table 2).

In the first stage, the DC resistance of a 100 km-long copper conductor is calculated using the following formula:

$$R_{DC} = \rho\, L/A = (1.72 \times 10^{-8}) * (100{,}000 / (300 \times 10^{-6})) = 5.73\ \Omega$$

In the second stage, the losses for an AC system are calculated, accounting for the skin effect; compared to the DC system, the resistance increases by approximately 10%:

$$R_{AC} = 1.10 * RDC = 5.73 * 1.10 = 6.30\ \Omega.$$

Table 2

Line length	L = 100 km (100,000 m)
Conductor material	Copper (Cu)
Conductor cross-section	A = 300 mm² (300 × 10^{-6} m²)
Current	I = 1000 A
Resistivity	ρ = 1.72 × 10^{-8} Ω·m
Effective increase in conductor resistance in an AC system	10%
Electricity price	80 USD/MWh

The active power losses of a three-phase AC line are calculated using expression (2):

$$P_{HVAC} = 3 * I^2 * R \quad (2)$$

Substituting the data into formula (2) yields:

$$P_{HVAC} = 3 * 1000^2 * 6.30 = 18.92 \text{ MW}.$$

In the third stage, the losses for an HVDC system are calculated for a bipolar HVDC line, which consists of two conductors—one for the positive pole and one for the negative pole [22]. Under steady-state conditions, the skin effect is practically negligible; therefore, the resistance for each pole is taken as 5.73 Ω. For a bipolar DC line with two conductors, the loss formula is as follows:

$$P_{HVDC} = 2 * I^2 * R \quad (3)$$

Accordingly, by substituting the data into formula (3), we obtain:

$$P_{HVDC} = 2 * 1000^2 * 5.73 = 11.47 \text{ MW}$$

Comparison of Results and Calculation of Economic Impact

To calculate the economic impact, it is necessary to determine the average price of electricity [23]. In Georgia, electricity pricing is differentiated; there are distinct rates for residential consumers, prices within the wholesale market, and an overall average market value for electricity [24]. Since 1 MWh = 1,000 kWh, the price per MWh is obtained by multiplying the price per kWh by 1,000. According to data from the Georgian National Energy and Water Supply Regulatory Commission (GNERC), the residential electricity tariffs effective from July 1, 2026, are as follows (Table 3).

Table 3

Monthly Consumption	Price, GEL/kWh	Price, GEL/MWh
0–101 kWh	0.197–0.203	197–203
101–301 kWh	0.237–0.241	237–241
Over 301 kWh	0.282–0.285	282–285

According to data from the Electricity Market Operator, the official exchange rate as of October 24, 2026-1 US Dollar ≈ 2.5971 GEL - is used to calculate these prices in US dollars (Table 4).
The price in the wholesale electricity market differs from the residential tariff. According to data from the Electricity Market Operator (ESCO), the weighted average price of balancing electricity in September 2026 was 16.0685 tetri/kWh. This corresponds to approximately: 0.161 GEL/kWh; 160.68 GEL/MWh; $0.062/kWh; and $61.85/MWh.

Table 4

Electricity Price	GEL/kWh	USD/ kWh	GEL/ MWh	USD/MWh
Average tariff for residential consumption	0.24	$0.092	240	$92.41
Average tariff for commercial consumption	0.285	$0.110	285	$109.73

For the initial economic calculation in this study, we can use 240 GEL/MWh as a benchmark based on the retail tariff, or approximately 161 GEL/MWh, based on the balancing market price from September 2026. However, to assess economic efficiency, it is preferable to use the actual wholesale purchase price while accounting for transmission losses, capital expenditures, and operational costs. For the purpose of this analysis, let us assume a unified average price of $80/MWh for all types of electricity transactions in Georgia [25]. As shown in the report, losses for alternating current (AC) are 18.92 MW, while losses for direct current (DC) are 11.47 MW. The difference in losses is:

$$\Delta P = 18.92 - 11.47 = 7.45 \text{ MW}.$$

Assuming the power transmission line operates continuously throughout the year, the annual savings would be:

$$\Delta E = 7.45 * 8760 = 65{,}289 \text{ MWh}.$$

If the assumed price of electricity is $80/MWh, multiplying the annual energy savings by this price yields:

$$S = 65{,}289 * 80 \approx \$5.22 \text{ million/year}.$$

Thus, using a DC line results in annual savings of $5.22 million. It should be noted that this represents an estimated economic difference derived solely from a simplified comparison of losses in the conductors, rather than the full investment advantage of a DC line. Furthermore, the comparison between a three-conductor AC system and a two-pole DC system does not imply that the systems operate at the same power and voltage levels. For a comprehensive economic assessment, it is necessary to consider scenarios with equivalent power transmission capacities and corresponding voltage conditions [26].

Conclusion

In an AC system, the skin effect increases the effective resistance of the AC conductor. In a DC system, under steady-state DC conditions, the current is distributed almost uniformly across the conductor's cross-section. In this example, AC losses were found to be higher when accounting for the skin effect; however, this difference is not solely attributable to the skin effect, as the number of conductors also varies. To determine the true economic advantage of a DC system, it is advisable to compare the costs of converter substations, as well as the capital and operational expenditures for the transmission line.

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ИСКУССТВЕННЫЙ ИНТЕЛЛЕКТ КАК ИНСТРУМЕНТ И ОБЪЕКТ КИБЕРАТАК: ВЫЗОВЫ ДЛЯ МОНИТОРИНГА ИНФОРМАЦИОННОЙ БЕЗОПАСНОСТИ В SOC

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Аннотация. Генеративный искусственный интеллект (ИИ) за 2024–2026 годы превратился из вспомогательного средства злоумышленников в исполнителя атак, а ИИ-агенты в корпоративной среде сами стали объектом атак. В статье на основе анализа отраслевых отчётов, задокументированных инцидентов и экспериментальных исследований предложена классификация ИИ-угроз по роли ИИ в атаке: ИИ как ускоритель (поиск и эксплуатация уязвимостей, генерация вредоносного кода), ИИ как средство обмана (персонализированный фишинг, дипфейки) и ИИ как цель (prompt injection, перехват агентов, атаки на цепочку поставок ИИ). Для каждого класса определено влияние на группы показателей эффективности мониторинга SOC и предложены меры адаптации. С помощью имитационной модели обработки оповещений показано, что сокращение времени атаки до 15 мин снижает долю истинных оповещений, квалифицированных до завершения атаки, с 99,9 % до 20,8 % в базовой конфигурации SOC; комбинация мер автоматизации повышает эту долю до 68,3 %. Сделан вывод, что ответ на ИИ-угрозы требует не только новых правил обнаружения, но и сокращения времени реакции до машинного масштаба, а также включения ИИ-агентов в периметр мониторинга как нечеловеческих учётных записей.

Ключевые слова: искусственный интеллект, SOC, ИИ-агенты, prompt injection, дипфейки, фишинг, MITRE ATLAS, мониторинг информационной безопасности.

Введение

Генеративный ИИ изменил экономику кибератак. По данным Check Point Cyber Security Report 2026, в 2025 году организации в среднем подвергались 1968 атакам в неделю, что на 70 % больше, чем в 2023 году; компания связывает рост с автоматизацией и использованием ИИ злоумышленниками [1]. В отчёте Check Point AI Security Report 2026 сделан более сильный вывод: ИИ перешёл от роли помощника при подготовке атак к роли исполнителя атаки [2]. Первым публично описанным случаем такого рода стала кампания GTG-1002, раскрытая компанией Anthropic: по её оценке, ИИ-агент выполнил 80–90 % тактических операций кибершпионажа против примерно 30 организаций [3].

Одновременно организации массово внедряют ИИ-агентов, которые читают почту, обращаются к файлам, тикетам и облачным ресурсам от имени сотрудников. Модели не

всегда разделяют данные и инструкции, поэтому содержимое, попавшее к агенту, способно изменить его поведение [2, 8]. Это создаёт новый класс атак, в которых целью является не пользователь и не сервер, а сам ИИ-агент.

Для центров мониторинга информационной безопасности (SOC) [13], роль которых в Республике Казахстан закреплена Законом «Об информатизации» [15], оба процесса означают одно: прежние правила обнаружения, источники телеметрии и нормативы времени реакции перестают соответствовать угрозам. В рамках исследования авторами разработаны методика интегральной оценки эффективности мониторинга и имитационная модель обработки оповещений в SOC. Настоящая статья применяет их к ИИ-угрозам.

Цель статьи – систематизировать угрозы, связанные с ИИ, и определить требования к адаптации процессов мониторинга ИБ в SOC. Задачи: 1) классифицировать ИИ-угрозы по роли ИИ в атаке; 2) оценить их влияние на группы показателей эффективности SOC; 3) количественно оценить влияние сокращения времени атаки на способность SOC реагировать вовремя; 4) предложить меры адаптации мониторинга.

Обзор литературы

ИИ в поиске и эксплуатации уязвимостей. Fang и соавт. [4] показали, что агент на основе GPT-4 при наличии описания уязвимости из CVE успешно эксплуатировал 87 % из 15 исследованных уязвимостей «одного дня»; без описания доля успеха снижалась до 7 %. По данным Check Point, ИИ используется для создания готовых к применению вредоносных программ и целых фреймворков: в одном случае разработчик с помощью среды ИИ-программирования создал фреймворк управления VoidLink объёмом 88 000 строк менее чем за неделю [2]. Это снижает порог входа в разработку сложных инструментов и затрудняет атрибуцию.

ИИ как средство обмана. Heiding и соавт. [5] в эксперименте со 101 участником сравнили фишинговые письма разных типов: доля переходов по ссылке составила 12 % для контрольной группы, 54 % для писем экспертов-людей и 54 % для полностью автоматизированных ИИ-писем. Собранные ИИ сведения о целях оказались точными и полезными в 88 % случаев, а автоматизация, по оценке авторов, повышает прибыльность фишинга до 50 раз. В 2024 году сотрудник компании Arup в Гонконге перевёл около 25 млн долларов США после видеоконференции, в которой финансовый директор и коллеги были дипфейками [6]. Check Point отмечает, что голос, лицо, документы и живое видео теперь подделываются достаточно дёшево, и виртуальная идентичность перестаёт быть надёжным основанием для доверия [2]. Обзор методов создания и обнаружения дипфейков представлен в [7].

ИИ как цель атаки. Greshake и соавт. [8] описали косвенную инъекцию промптов (indirect prompt injection): злоумышленник размещает инструкции в данных, которые ИИ-приложение затем извлекает и обрабатывает. OWASP относит инъекцию промптов к главному риску LLM-приложений, а избыточные полномочия агентов (excessive agency) выделяет в отдельный риск [9]. Тактики атак на системы ИИ систематизированы в матрице MITRE ATLAS [10] и таксономии NIST AI 100-2 [11]. Для оценки устойчивости агентов к инъекциям предложены специализированные среды, например AgentDojo [12]. Данные Check Point подтверждают переход этих атак в практику: число обнаружений длинных вредоносных payload'ов косвенной инъекции выросло примерно в 5 раз с марта по май 2026 года и приблизилось к 1 % наблюдаемых промптов [2]. По оценке Lakera, слабые места безопасности найдены у 40 % из 10 000 проверенных серверов Model Context Protocol (MCP), через которые агенты подключаются к инструментам [1].

Обзор показывает, что отдельные классы ИИ-угроз хорошо изучены, но их последствия для процессов мониторинга SOC – какие показатели ухудшаются и какие меры нужны – рассматриваются фрагментарно.

Материалы и методы

Исследование выполнено в три этапа. На первом этапе проведён контент-анализ отраслевых отчётов 2025–2026 годов [1–3], экспериментальных исследований [4, 5, 8, 12] и описаний инцидентов [3, 6]. Угрозы сгруппированы по роли ИИ в атаке и сопоставлены с тактиками MITRE ATT&CK [14] и MITRE ATLAS [10].

На втором этапе для каждого класса угроз определено, на какие группы показателей интегральной оценки эффективности SOC он влияет: K1 – покрытие техник атак, K2 – полнота телеметрии, K3 – точность обнаружения, K4 – оперативность, K5 – нагрузка на аналитиков.

На третьем этапе с помощью дискретно-событийной имитационной модели первой линии SOC оценено, как сокращение времени атаки влияет на способность SOC отреагировать вовремя. Модель описывает SOC как систему массового обслуживания с 4 аналитиками, потоком 20 оповещений в час и долей ложных оповещений 85 %. Рассчитывалась доля истинных оповещений, квалификация которых завершена не позже времени T_a – времени от первого обнаруживаемого действия злоумышленника до достижения им цели:

$$P(T_a) = P(W + S \leq T_a) \qquad (1)$$

где W – время ожидания оповещения в очереди, S – время его квалификации аналитиком. Значения T_a = 240 и 120 мин соответствуют темпу атаки, управляемой человеком, значения 30 и 15 мин – атаке с «машинной скоростью». Сравнивались базовая конфигурация SOC (S0), приоритизация по риску (S4) и комбинация мер автоматизации (S5): сокращение потока ложных оповещений на 40 %, SOAR-обогащение с сокращением времени квалификации на 30 %, автоматическое закрытие 50 % ложных оповещений с ошибкой 1 % и приоритизация по риску; для каждой выполнено 10 прогонов по 30 суток.

Результаты

Классификация ИИ-угроз. Угрозы разделены на три класса (таблица 1). Первые два класса усиливают известные техники ATT&CK, третий образует новую поверхность атаки, описываемую матрицей ATLAS.

Таблица 1 – Классификация угроз, связанных с ИИ

Класс	Угрозы	Подтверждающие данные	Тактики ATT&CK / ATLAS
А. ИИ как ускоритель атаки	Поиск и эксплуатация уязвимостей; генерация вредоносного кода; автономное выполнение этапов вторжения	87 % успешных эксплуатаций при наличии CVE [4]; фреймворк 88 000 строк менее чем за неделю [2]; 80–90 % операций выполнено ИИ [3]	Reconnaissance, Initial Access, Execution, Lateral Movement
Б. ИИ как средство обмана	Персонализированный фишинг; голосовой фишинг ИИ-агентами; дипфейки голоса и видео	54 % переходов против 12 % [5]; перевод около 25 млн долл. после дипфейк-видеозвонка [6]; ClickFix +500 % [1]	Reconnaissance, Phishing (T1566), Impersonation (T1656)
В. ИИ как цель атаки	Прямая и косвенная инъекция промптов; перехват агентов через отравленные данные и конфигурации; уязвимости MCP-серверов и цепочки поставок ИИ	Рост обнаружений инъекций в 5 раз за 2 месяца [2]; 40 % из 10 000 MCP-серверов со слабыми местами [1]	ATLAS: LLM Prompt Injection (AML.T0051), LLM Jailbreak (AML.T0054), AI Supply Chain Compromise (AML.T0010)

Влияние на показатели эффективности SOC. Каждый класс ухудшает несколько групп показателей (таблица 2). Наиболее уязвима группа К4 «Оперативность», так как класс А сокращает время, отведённое на реакцию. Класс В создаёт пробел в группе К2: действия ИИ-агентов – промпты, вызовы инструментов, обращения к MCP-серверам – обычно не поступают в SIEM.

Таблица 2 – Влияние классов ИИ-угроз на группы показателей SOC

Группа показателей	Класс А	Класс Б	Класс В
К1 Покрытие техник	Быстрое появление новых вариантов кода снижает эффективность сигнатурных правил	Обход проверки личности по голосу и видео не покрыт правилами	Техники ATLAS отсутствуют в каталогах правил
К2 Полнота телеметрии	–	Голосовые каналы и мессенджеры вне SIEM	Журналы агентов, промптов и MCP не собираются
К3 Точность	Атаки маскируются под легитимную автоматизацию	Персонализированные письма проходят фильтры	Вредоносные действия агента выглядят как штатная работа
К4 Оперативность	Время атаки сокращается до минут	Ущерб наступает за одну сессию звонка	Агент выполняет действия без участия человека
К5 Нагрузка	Рост числа атак увеличивает поток оповещений	Рост числа обращений по подозрительным письмам	Новые источники событий увеличивают поток

Влияние времени атаки на реакцию SOC. Результаты расчёта по формуле (1) приведены в таблице 3. При темпе атаки, управляемой человеком (T_a = 4 ч), базовый SOC успевает квалифицировать 99,9 % истинных оповещений. При «машинной скорости» (T_a = 15 мин) эта доля падает до 20,8 %.

Таблица 3 – Доля истинных оповещений, квалифицированных до завершения атаки, %

Конфигурация SOC	T_a = 15 мин	T_a = 30 мин	T_a = 60 мин	T_a = 120 мин	T_a = 240 мин
S0 Базовая (4 аналитика)	20,8	47,4	79,4	97,1	99,9
S4 Приоритизация по риску	36,1	67,3	87,7	96,7	99,8
S5 Комбинация мер, 4 аналитика	68,3	90,5	98,5	99,8	100,0
S5 Комбинация мер, 2 аналитика	54,8	82,7	96,3	99,6	100,0

Комбинация мер автоматизации повышает долю своевременно квалифицированных оповещений при T_a = 15 мин в 3,3 раза (с 20,8 до 68,3 %). Для S5 доли рассчитаны без учёта около 1 % истинных оповещений, ошибочно закрытых автоматически. Даже в лучшей конфигурации почти треть атак с машинной скоростью завершается раньше, чем аналитик заканчивает квалификацию.

Обсуждение

Результаты таблицы 3 показывают, что при атаках с машинной скоростью узким местом становится не обнаружение, а время между оповещением и решением человека. Даже при отсутствии очереди квалификация истинного оповещения аналитиком занимает в модели в среднем 14–20 мин, что сопоставимо со всем временем атаки. Следовательно, для части сценариев сдерживание должно запускаться автоматически – изоляция узла, блокировка учётной записи, отзыв токена агента – с последующей проверкой человеком. Этот вывод согласуется с рекомендацией Check Point ставить предотвращение выше реагирования [1] и с позицией Anthropic о необходимости применять ИИ для автоматизации SOC и реагирования [3].

По результатам анализа предложены меры адаптации мониторинга по классам угроз:

1) для класса А – поведенческие правила обнаружения вместо сигнатурных, сокращение окна между публикацией CVE и установкой исправлений, автоматическое сдерживание для правил высокой точности;

2) для класса Б – внеполосное подтверждение платёжных и кадровых операций по заранее известному каналу, отказ от голоса и видео как единственного фактора проверки личности, сбор событий голосовых каналов и мессенджеров;

3) для класса В – учёт ИИ-агентов как нечеловеческих учётных записей с минимальными полномочиями, журналирование промптов, вызовов инструментов и обращений к MCP-серверам с передачей в SIEM, подтверждение человеком необратимых действий агента, дополнение каталога правил техниками MITRE ATLAS.

Меры класса В связаны с группой К2 «Полнота телеметрии»: пока действия агентов не попадают в SIEM, никакие правила не смогут их обнаружить. Поэтому журналирование агентов следует рассматривать как первоочередной шаг, а правила обнаружения – как второй.

Ограничения исследования: отраслевые отчёты [1, 2] публикуются производителями средств защиты и не проходят независимого рецензирования; эксперименты [4, 5] выполнены на ограниченных выборках; параметры имитационной модели являются допущениями. Выводы следует уточнять по мере появления независимой статистики инцидентов.

Заключение

В статье предложена классификация угроз, связанных с ИИ, по роли ИИ в атаке: ускоритель, средство обмана и цель. Первые два класса усиливают известные техники и прежде всего ухудшают оперативность и точность обнаружения; третий класс создаёт новую поверхность атаки, которая не покрыта телеметрией и правилами большинства SOC. Моделирование показало, что сокращение времени атаки с 4 ч до 15 мин снижает долю своевременно квалифицированных истинных оповещений с 99,9 % до 20,8 % в базовом SOC; автоматизация повышает её до 68,3 %, но не устраняет разрыв полностью. Отсюда следуют три требования к SOC: автоматическое сдерживание для правил высокой точности, внеполосная проверка операций, уязвимых для дипфейков, и включение ИИ-агентов в периметр мониторинга как нечеловеческих учётных записей с журналированием их действий. Дальнейшие исследования направлены на разработку правил обнаружения для техник MITRE ATLAS и их проверку на стенде с ИИ-агентами.

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A TWO-STAGE EDGE-SERVER FRAMEWORK FOR REAL-TIME ROAD DAMAGE DETECTION USING DEEP NEURAL NETWORKS

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Abstract. Timely detection of road surface defects is a prerequisite for proactive road maintenance, yet manual visual inspection remains slow, costly and subjective. Deep neural networks make automated detection from vehicle-mounted cameras and smartphones feasible, but detector families differ substantially in computational cost, and the model that is most suitable for a server is rarely suitable for an edge device. This paper analyses the deployment trade-offs of three representative detectors, YOLOv5s (single-stage), Faster R-CNN (two-stage) and Mask R-CNN (instance segmentation), for road damage detection on the RDD2020 dataset. An analysis of the dataset (21,041 images, eight damage types) shows a strong class imbalance of about 186:1 between the most and the least frequent class. Published results under the protocol of the Global Road Damage Detection Challenge show that single YOLOv5 and Faster R-CNN models reach comparable F1-scores (0.47-0.54). Inference measurements on an Apple M1 Pro laptop show that YOLOv5s processes 36 FPS on the integrated GPU and is 3.8 and 11.5 times faster on CPU than Faster R-CNN and Mask R-CNN, respectively, while having about six times fewer parameters. Based on these findings, a two-stage edge-server framework is proposed in which a lightweight detector performs real-time screening on the edge device and a region-based model performs detailed assessment on a municipal server. A deployment decision matrix and practical recommendations for cities of Kazakhstan, such as Almaty, are presented.

Keywords: road damage detection, deep neural networks, real-time object detection, YOLOv5, Mask R-CNN, edge computing, smart city, infrastructure monitoring.

1. Introduction

Road infrastructure is one of the most valuable public assets of any country, and its condition directly affects traffic safety, vehicle operating costs and logistics efficiency. Cracks and potholes that are not repaired in time grow rapidly under traffic load and weather exposure, so the cost of repair rises sharply the later a defect is detected. In most cities, however, road condition is still assessed by periodic manual surveys, which are labour-intensive, infrequent and dependent on the experience of individual inspectors.

Kazakhstan faces this problem in a particularly acute form. Its road network extends over a vast territory with a sharply continental climate, and large daily and seasonal temperature differences together with repeated freeze-thaw cycles accelerate the deterioration of asphalt pavement. Automated, camera-based monitoring therefore offers clear practical value: municipal vehicles, public transport and even private drivers equipped with smartphones could continuously collect road imagery at almost no additional cost.

Advances in deep learning, and in convolutional object detectors in particular, have made such monitoring technically feasible [1, 2]. The practical difficulty lies elsewhere: detectors differ

substantially in accuracy, speed and hardware requirements, and the architecture that performs best in a benchmark is not necessarily the one that can be deployed on a smartphone or an in-vehicle computer. The purpose of this paper is to quantify the computational cost of representative detector families under identical conditions and to propose a deployment-oriented framework that combines the strengths of different architectures instead of choosing a single model.

The contributions of the paper are as follows: (1) a reproducible measurement of the inference cost of three representative detector families on laptop-class hardware; (2) an analysis of the class composition of RDD2020 and its implications for training; (3) a two-stage edge-server framework and a deployment decision matrix that map operational constraints to the choice of model.

2. Related work

Maeda et al. [1] demonstrated that road damage can be detected and classified from smartphone images using deep neural networks and released one of the first large public datasets for this task. This work led to the Global Road Damage Detection Challenge and to the multi-national RDD2020 dataset, which contains images from Japan, India and the Czech Republic annotated with longitudinal cracks, transverse cracks, alligator cracks and potholes [3]. Its successor, RDD2022, extended the data to further countries and confirmed that models trained on one country do not transfer perfectly to another [4], which is directly relevant to regions such as Central Asia that are not represented in existing datasets.

Three families of detectors are commonly applied to the task. Single-stage detectors of the YOLO family [5, 6] predict boxes and classes in one pass and are optimised for speed. Two-stage detectors such as Faster R-CNN [7] first generate region proposals and then classify them, which usually improves localisation accuracy at the cost of latency. Instance-segmentation models such as Mask R-CNN [8] additionally predict a pixel mask for each object, enabling estimation of the damaged area. This information is valuable for repair planning but computationally expensive. More recent approaches, including EfficientDet [9] and transformer-based real-time detectors such as RT-DETR [10], aim to improve this trade-off further. Arya et al. [2] showed that solutions to the road damage challenge are typically evaluated on accuracy alone, while deployment constraints such as model size, latency and memory receive considerably less attention. The present work addresses this gap.

3. Materials and methods

Dataset. The study uses the training part of the RDD2020 dataset [3], the only part released with annotations: 21,041 images captured by vehicle-mounted smartphones in Japan (10,506), India (7,706) and the Czech Republic (2,829). Eight road damage types annotated in the dataset were used: longitudinal crack (D00), longitudinal construction joint (D01), transverse crack (D10), transverse construction joint (D11), alligator crack (D20), pothole (D40), crosswalk blur (D43) and white line blur (D44). Manhole covers (D50) were excluded because they are road furniture rather than damage. The images were split at random into training, validation and test subsets in the ratio 80/10/10 with a fixed seed (16,832, 2,104 and 2,105 images, respectively). In parallel, more than 3,000 additional images of road damage are being collected in Almaty for subsequent adaptation of the models to local conditions.

Models. Three architectures representing the main detector families were compared: YOLOv5s [6] (single-stage, small variant), Faster R-CNN [7] (two-stage) and Mask R-CNN [8] (instance segmentation). Both region-based models use a ResNet-50-FPN backbone. All models were configured for the eight damage classes.

Metrics. Efficiency was measured by inference latency (mean and 95th percentile), throughput in frames per second (FPS), number of parameters and model size on disk. Detection

accuracy will be evaluated on the held-out test subset with mAP@0.50 and mAP@0.50:0.95 following the COCO methodology [11].

Inference benchmark. Inference efficiency was measured on an Apple MacBook Pro with an M1 Pro chip and 16 GB of unified memory (macOS, PyTorch 2.8, torchvision 0.23). This laptop-class hardware without a discrete GPU was chosen deliberately as a proxy for edge devices. All models were evaluated with a single 640x640 input (batch size 1) after warm-up runs; latency was averaged over 100 runs on the integrated GPU (Metal Performance Shaders backend) and over 20 runs on the CPU. Faster R-CNN and Mask R-CNN were implemented with a ResNet-50-FPN backbone and default torchvision post-processing (up to 100 detections per image), so their timings include region proposal, non-maximum suppression and, for Mask R-CNN, mask prediction. For YOLOv5s, the forward pass of the network was timed. Because inference cost depends on the architecture and input size rather than on the values of the weights, these measurements characterise the deployment cost of the trained models.

4. Results and analysis

Inference efficiency. The measured inference cost is summarised in Table 3. YOLOv5s has 7.0 M parameters against 41.4 M and 44.0 M for Faster R-CNN and Mask R-CNN; its FP32 weights occupy 28.4 MB (about 14 MB in the half-precision checkpoint format used by YOLOv5). On the integrated GPU of the M1 Pro, YOLOv5s reached 36 FPS (27.7 ms per frame, 95th percentile 30.5 ms), which is sufficient for real-time processing of a typical 25-30 FPS dash-camera stream. On the CPU, YOLOv5s ran at 9.2 FPS, whereas Faster R-CNN and Mask R-CNN reached only 2.4 and 0.8 FPS. Thus, YOLOv5s is the only one of the three models suitable for real-time processing on resource-constrained hardware, while the region-based models require server-class GPUs or offline processing.

Dataset characteristics. The eight classes contain 31,120 annotated objects in total, but their distribution is highly uneven (Table 1). Alligator cracks (26.9%), longitudinal cracks (21.2%) and potholes (18.1%) dominate, whereas construction joints are almost absent: transverse joints (D11) account for only 45 objects, i.e. 0.1% of all annotations, which gives an imbalance ratio of about 186:1. In addition, about one third of the images contain no damage of the eight types. For training this means that rare classes will be learned poorly regardless of the architecture unless class-balanced sampling, loss re-weighting or additional data are used, and that per-class metrics must be reported alongside the overall mAP, because the latter is dominated by the frequent classes.

Table 1. Class distribution in the annotated part of RDD2020 (21,041 images)

Code	Damage type	Objects	Share, %
D00	Longitudinal crack	6,592	21.2
D01	Longitudinal construction joint	179	0.6
D10	Transverse crack	4,446	14.3
D11	Transverse construction joint	45	0.1
D20	Alligator crack	8,381	26.9
D40	Pothole	5,627	18.1
D43	Crosswalk blur	793	2.5
D44	White line blur	5,057	16.2
	Total	31,120	100.0

Reported detection accuracy. Published results on RDD2020 obtained under the protocol of the Global Road Damage Detection Challenge 2020 (four damage classes D00, D10, D20 and

D40; F1-score on two hidden test sets) are summarised in Table 2. Single models of both families reach comparable accuracy: a single YOLOv5s achieved an F1-score of 0.47-0.49 and Faster R-CNN with ResNet-50 to ResNeXt-101 backbones 0.51-0.54 [14, 15], while the best result, 0.67, was obtained by an ensemble of YOLOv5 models with test-time augmentation [13]. Thus, the accuracy difference between the light single-stage detector and the heavier two-stage detector is small compared with the difference in computational cost reported below (Table 3), and it can be reduced by ensembling and tuning. These values are not directly comparable with the eight-class setting of the present study and serve as a reference point.

Table 2. Published detection accuracy on RDD2020 (GRDDC 2020 protocol, four classes)

Model	Source	F1, test 1	F1, test 2
YOLOv5 ensemble + TTA (1st place)	Arya et al. [13]	0.675	0.666
Cascade R-CNN ensemble (3rd place)	Arya et al. [13]	0.629	0.622
YOLOv5x, single model	Arya et al. [13]	0.568	0.571
Faster R-CNN, ResNet-101	Vishwakarma et al. [14]	0.537	0.534
Faster R-CNN, ResNet-50	Vishwakarma et al. [14]	0.529	0.543
Faster R-CNN, ResNeXt-101-FPN	Pham et al. [15]	0.510	0.514
YOLOv5s, single model	Vishwakarma et al. [14]	0.486	0.470

Table 3. Inference efficiency on Apple M1 Pro CPU (input 640x640, batch size 1)

Model	Params, M	Size, MB (FP32)	CPU latency, ms	CPU FPS
YOLOv5s	7.0	28.4	108.5	9.2
Faster R-CNN R50-FPN	41.4	165.9	412.5	2.4
Mask R-CNN R50-FPN	44.0	176.4	1248.2	0.8

Practical implications. Two consequences follow. First, the choice of model should be driven by the operating scenario: real-time screening and detailed assessment are different tasks with different constraints. Second, because only a minority of video frames contain damage, a fast lightweight model can handle the high-volume first stage of monitoring, while slower region-based models, which are generally reported to localise objects more precisely [7, 8], can be reserved for the comparatively small number of frames that actually contain damage.

5. Proposed two-stage edge-server framework

Based on the above analysis, a two-stage framework is proposed (Fig. 1). In the first stage, a lightweight detector (YOLOv5s) runs directly on a smartphone or an in-vehicle computer and processes the video stream in real time. Frames in which damage is detected with sufficient confidence are tagged with GPS coordinates and time and uploaded to the server; all other frames are discarded. This substantially reduces the volume of transmitted data and allows monitoring over ordinary mobile networks. The measurements in Table 3 also show why the filtering is necessary: Mask R-CNN on a CPU processes about 0.8 frames per second, i.e. roughly 2% of a 36

FPS stream, so a server can keep up with a vehicle only if the edge stage forwards a small fraction of frames.

In the second stage, the municipal server applies a region-based model to the uploaded frames: Faster R-CNN for precise localisation and classification or, once mask annotations are available, Mask R-CNN to obtain pixel-level masks, from which the damaged area and a severity level are estimated. The results are aggregated on a GIS map and in the road registry and are used to prioritise repairs. Repeated passes along the same road make it possible to track how defects develop over time and to schedule maintenance before minor cracks turn into potholes.

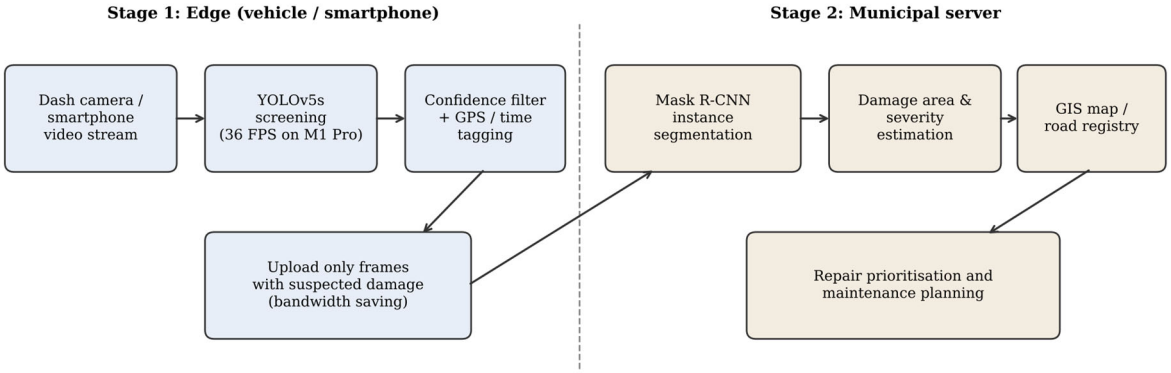


Figure 1. Architecture of the proposed two-stage edge-server framework

The choice of model for different operating scenarios is summarised in the deployment decision matrix (Table 4).

Table 4. Deployment decision matrix

Scenario	Main constraint	Recommended model	Rationale
Mobile / edge screening (smartphone, dash camera)	Real-time speed, small memory, no stable network	YOLOv5s	36 FPS on laptop GPU, 9.2 FPS on CPU; 6x fewer parameters
Municipal server analysis	Balance of accuracy and processing cost	Faster R-CNN or Mask R-CNN	Region-based localisation on a small share of frames; GPU available
Detailed / forensic assessment (repair planning, claims)	Maximum accuracy, damage area required	Mask R-CNN	Pixel masks for area estimation; highest computational cost
City-wide continuous monitoring (e.g. Almaty)	Coverage, bandwidth, cost	Two-stage pipeline: YOLOv5s + Mask R-CNN	Combines real-time coverage with accurate server-side assessment

6. Discussion and limitations

The framework is deliberately architecture-agnostic: the edge detector can be replaced by a newer lightweight model and the server model by a stronger segmentation network without changing the overall design. Further acceleration on the edge can be obtained through integer quantization of the network [12], which typically reduces model size and latency with a small loss of accuracy.

The main limitation of the present study is that the accuracy comparison relies on published results obtained under the four-class challenge protocol; the per-class accuracy of YOLOv5s and Faster R-CNN on the eight-class split described above will be presented in future work. Training Mask R-CNN additionally requires pixel-level annotations, which RDD2020 does not provide, so masks will have to be produced for a subset of the data. A second limitation is the domain gap. RDD-2020 does not include roads of Kazakhstan, where snow cover, de-icing materials, dust and low winter sun produce visual conditions that differ from those in the training data. The locally collected images will be used for fine-tuning and for evaluating how well the models generalise to these conditions. In addition, the inference measurements were obtained on a single laptop platform; smartphones and embedded boards may differ, and the measured YOLOv5s time does not include image decoding and post-processing. The recall of the screening stage, the share of forwarded frames and the end-to-end latency of the proposed pipeline still need to be measured in field tests on real vehicles. Finally, area estimates derived from masks in perspective images are approximate unless the camera is calibrated.

7. Conclusion

The paper analysed the deployment trade-offs of single-stage, two-stage and instance-segmentation neural networks for road damage detection. Measurements on a laptop-class device showed that YOLOv5s is the only one of the three models capable of real-time inference without a discrete GPU (36 FPS on the Apple M1 Pro GPU) and that it is 3.8 and 11.5 times faster than Faster R-CNN and Mask R-CNN on CPU. Published results on RDD2020 show that single YOLOv5 and Faster R-CNN models differ only moderately in F1-score (0.47-0.54), so for edge deployment the computational cost becomes the decisive factor. The analysis of RDD2020 revealed a class imbalance of about 186:1, which makes per-class evaluation and imbalance-aware training necessary. Instead of selecting a single “best” network, a two-stage edge-server framework was proposed in which real-time screening on the edge is combined with detailed region-based analysis on a server, together with a decision matrix for different deployment scenarios. Future work will report the per-class detection accuracy of the models, fine-tune them on road imagery from Kazakhstan and validate the complete pipeline in field tests in Almaty.

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A DEPLOYABLE REAL-TIME SERVICE FOR EARLY CARD-FRAUD SCORING WITH FEW LABELS AND A SELF-SUPERVISED NOVELTY INDICATOR

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Abstract. Fraud detection models must start working when only a few confirmed fraud labels exist, and they must score each payment within the time budget of card authorisation. This paper describes the software design of a real-time fraud scoring service that meets both requirements. The risk model was selected on a validation period, without using test data, from candidates that included self-supervised representations; the selected model is a random forest on 31 decision-time features. The self-supervised component is kept as a separate novelty indicator. On 284 807 real card transactions, a model trained on the labels of only the first three hours of operation reached an area under the precision–recall curve of 0.770 on transactions more than 33 hours later. The service has authenticated REST endpoints, schema validation, checksum-protected model artifacts and mid-rank calibration of scores, and its 99-th percentile HTTP latency was 9.6 ms.

Keywords: fraud detection, real-time scoring, cold start, random forest, self-supervised learning, REST API.

Introduction. Payment fraud is a large and growing problem. Worldwide card fraud losses were estimated at 33.83 billion US dollars in 2023 [3], and in Kazakhstan the National Bank created an Anti-Fraud Centre in which each bank and payment organisation remains responsible for its own detection decisions [10]. Research on fraud detection usually concentrates on model accuracy, measured on large labelled datasets with random splits [1]. A deployed system faces two additional constraints. First, labels are scarce and delayed: a transaction is confirmed as fraud only after a complaint and an investigation [5], so a new product or a new institution must start with very few labels. Second, the score is needed synchronously, while the payment is being authorised, so the whole pipeline must run in milliseconds.

This paper reports the software engineering part of a master's thesis on early fraud detection. It answers three practical questions: how to choose the risk model honestly when labels are scarce, how to use a self-supervised representation in production without harming detection, and how to package the model as a secure, low-latency service.

Data and model selection. The study uses the public card-transaction dataset of the Machine Learning Group of ULB [6], obtained from OpenML (ID 1597) [11]. It contains 284 807 transactions over two days, with 492 frauds (0.17%). Each transaction is described by 28 anonymised principal components, log(1 + amount) and the hour of day encoded as sine and cosine, i.e. 31 features available at authorisation time. The data are split strictly by time: the first 60% of transactions form the training period, the next 10% the validation period and the last 30% the test period, which imitates deployment and avoids leakage from the future [8].

Several candidate scoring layers were compared on the validation period only: a random forest [2] and XGBoost [4] on raw features, forests that also receive embeddings of a self-

supervised encoder, linear probes on the embeddings, a nearest-labelled-fraud score and a self-training variant. The random forest on raw features had the highest validation AUPRC at every labelling budget and was therefore selected; the test period was used only to report its performance. The self-supervised encoder, trained without labels on the training period with a combined contrastive and reconstruction objective, did not improve the risk score, but its embedding is used for the novelty indicator described below.

The selected model is especially useful at the start of a deployment. When labels were taken only from the first H hours of operation, the random forest reached a test AUPRC of 0.770 with H = 3 hours (25 labelled frauds) and 0.822 with the complete 33.5-hour history (Table 1). Thus 94% of the final quality is available after three hours of labelled operation.

Table 1 – Test AUPRC when labels come only from the first H hours of operation (mean over five seeds)

Labelled history	3 h	6 h	12 h	24 h	33.5 h
Labelled frauds	25	55	146	281	360
Random forest, raw features	0.770	0.779	0.801	0.812	0.822
XGBoost, raw features	0.724	0.648	0.745	0.791	0.807

Service architecture. The software consists of an offline pipeline and an online service connected only by versioned artifacts (Figure 1). The offline pipeline trains the encoder and the random forest and exports them; the online service, written with FastAPI, loads the artifacts once per process and scores requests. Because PyTorch and XGBoost bundle conflicting OpenMP runtimes on macOS and crashed when used in one process, the offline pipeline runs them in separate processes and exchanges data through files.

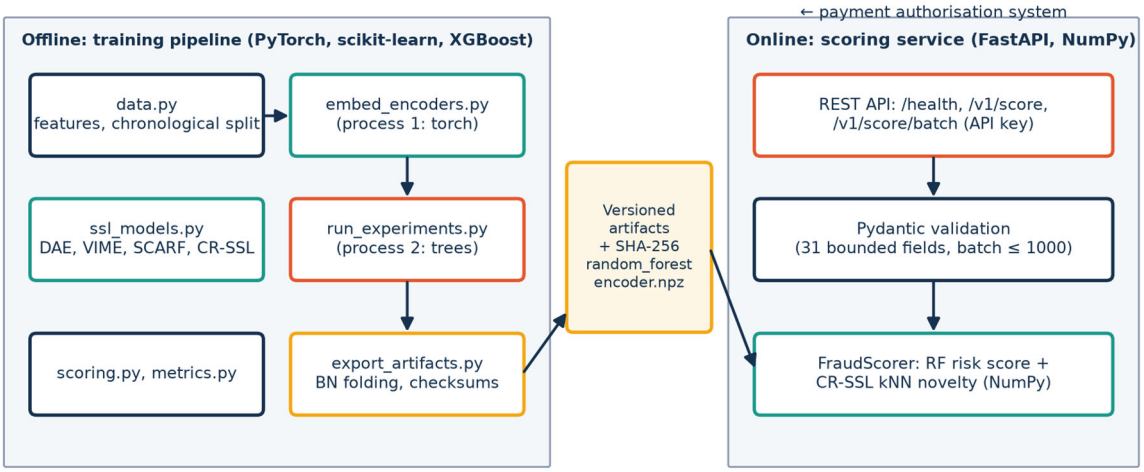


Figure 1 – Software architecture: offline training pipeline, versioned artifacts with SHA-256 checksums, and the online scoring service

Three design decisions make the service suitable for production. First, the encoder does not require PyTorch at inference time: each linear layer and its batch-normalisation layer are folded into one affine transformation, and the resulting NumPy encoder matches the original network to within $1.1 \cdot 10^{-5}$. Second, scores are calibrated with a mid-rank empirical distribution function computed on the validation period, $r(s) = \tfrac{1}{2}(|\{s' < s\}| + |\{s' \le s\}|) / n$. A plain distribution function assigned a misleading percentile of 0.91 to a typical legitimate payment, because many validation transactions receive a forest probability of exactly zero; the mid-rank version gives 0.455

for the same payment. The calibrated score is mapped to three levels: HIGH above the 99.9-th percentile of legitimate validation scores (about 0.1% false positives), MEDIUM above the 99-th percentile, and LOW otherwise. Third, the self-supervised component is reported separately as a novelty percentile, the rank of the mean distance from the transaction to its ten nearest neighbours among 20 000 unlabeled training transactions in the embedding space. Mixing this unsupervised score into the risk score lowered AUPRC in the thesis experiments, which agrees with findings that self-supervised representations do not improve tabular anomaly detection over raw features [9]; as a separate signal it helps analysts and can reveal data drift.

Interface and security. The service exposes GET /health, POST /v1/score for one transaction and POST /v1/score/batch for up to 1 000 transactions. Each response contains the risk score, the risk level, the forest probability, the novelty percentile and the model version. Scoring endpoints require an API key that is read from an environment variable and compared in constant time; the service refuses to score if no key is configured. The request schema forbids unknown fields and bounds every input, so malformed requests are rejected before they reach the model. Because the random forest is stored with joblib, which uses Python pickle, the service checks the SHA-256 checksum of every artifact before loading it and refuses to start on a mismatch. The log records only the risk level, never the transaction features, in line with the Law of the Republic of Kazakhstan on personal data [7].

Testing and performance. The project was developed test-first: 19 unit tests cover feature engineering, chronological splitting, metrics, corruption and loss functions, and 9 API tests cover authentication, validation, batch limits, tampered artifacts and tie handling in calibration; all 28 tests pass. Latency was measured on a laptop with an Apple M4 processor while other experiments were running (Table 2). Setting the forest to single-threaded inference halved the single-request latency, because starting a thread pool for every request dominated the cost.

Table 2 – Measured latency of the scoring service

Measurement	p50, ms	p95, ms	p99, ms
Scorer, one transaction	6.93	7.38	7.66
Full HTTP request	9.08	9.48	9.64
Batch of 2 000, per transaction	0.26	–	–

Conclusion. A fraud scoring service for the early phase of a deployment was designed, implemented and tested. Selecting the risk model on a validation period produced a random forest that reaches 94% of its final quality after three hours of labelled operation. The self-supervised encoder is used where it is helpful, as a separate novelty indicator, and not where it reduced quality. Folding batch normalisation, mid-rank calibration, checksum-protected artifacts and validated, authenticated endpoints give a service with a 99-th percentile latency below 10 ms that can be called synchronously during card authorisation. Future work includes evaluation on data with raw transaction features and integration with an analyst feedback loop for frequent retraining.

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Production and Characterization of Fuel Briquettes from Saran Coal Sludge and Cattle Waste

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Keywords: Saran coal sludge, cattle waste, biomass, fuel briquettes, calorific value, mechanical strength.

Background. The joint processing of coal sludge and cattle waste is considered a means of producing briquetted fuel from secondary raw materials. Formulation selection requires consideration of both energy performance and resistance to mechanical stresses. Moisture content, feedstock preparation, and compaction conditions influence the quality of the resulting fuel [1].

Objective. To compare the energy and mechanical properties of briquettes produced from Saran coal sludge and from a blend of this sludge with cattle waste as the biomass component.

Materials and Methods. Two formulations were considered: C-1 consisted of Saran coal sludge without added biomass, whereas C-2 contained 70% Saran coal sludge and 30% cattle waste by mass of the fuel blend. The coal component was sludge from the Saran coal preparation plant. The 70:30 ratio describes the blend formulation; conversion to a dry-mass basis requires the moisture content of each component at the time of proportioning.

The process comprises feedstock preparation and proportioning, mixing, forming, conditioning, and drying. The comparison was based on the test results reported in the source materials for samples No. 1 and No. 2, designated C-1 and C-2, respectively, in reports issued by the testing laboratory of NPTS Ugol LLP on 19 January 2026 [2, 3]. The properties assessed were moisture content, ash content, volatile matter, sulfur content, calorific value, and drop resistance.

Table 1. Properties of the investigated briquettes [2,3]

Property	C-1	C-2
Total moisture content, as-received basis, %	18.14	8.61
Ash content, dry basis, %	47.66	48.59
Volatile matter, dry, ash-free basis, %	35.77	33.31
Total sulfur conent, dry, ash-free basis, %	1.41	1.46
Gross calorific value, dry, ash-free basis, MJ/kg	31.857	31.400
Net calorific value, as-received basis, MJ/kg	12.752	13.988
Drop resistance, %	67	63

Results and Discussion. The net calorific value of C-2 on an as-received basis was 13.988 MJ/kg, exceeding that of C-1 by 1.236 MJ/kg, or 9.69%. However, the moisture content of C-2 was 9.53 percentage points lower. The observed difference therefore cannot be attributed solely to the incorporation of 30% cattle waste: the effects of composition and moisture content must be evaluated under comparable conditions. The ash content of C-2 exceeded that of C-1 by 0.93 percentage points, while its total sulfur content was 0.05 percentage points higher. Thus, in these tests, biomass addition was not accompanied by a reduction in either ash or sulfur content. The gross calorific value of C-2 on a dry, ash-free basis was 0.457 MJ/kg lower. These findings demonstrate the need to distinguish between calorific values expressed on an as-received basis and those expressed on a dry, ash-free basis.

Drop resistance was 67% for C-1 and 63% for C-2. Although the cattle-waste blend exhibited a higher net calorific value on an as-received basis, its drop resistance was 4 percentage points lower than that of the coal-sludge-only formulation. Formulation selection therefore requires a combined assessment of calorific value, moisture content, and briquette integrity during transportation and storage.

Conclusions. Formulation C-2, comprising 70% Saran coal sludge and 30% cattle waste, merits further investigation as an approach to the joint processing of coal and livestock wastes. The reported results indicate a higher net calorific value on an as-received basis for C-2, whereas C-1 exhibited greater drop resistance. Repeated tests at the same moisture content and under uniform forming and drying conditions are required to confirm any advantages of the blend. The available results do not establish the 70:30 ratio as optimal.

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DAŞINMAZ ƏMLAKIN KÜTLƏVİ QİYMƏTLƏNDİRİLMƏSİNİN METOD VƏ ALQORİTMLƏRİ

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XÜLASƏ:Məqalədə daşınmaz əmlakın kütləvi qiymətləndirilməsi prosesinin nəzəri və metodoloji əsasları araşdırılır, mənzillərin bazar dəyərinin müəyyən edilməsində müasir riyazi modellərin və maşın öyrənməsi alqoritmlərinin tətbiqi imkanları təhlil olunur. Tədqiqat çərçivəsində hedonik reqressiya, Random Forest və Gradient Boosting metodlarının qiymətləndirmə prosesində istifadə xüsusiyyətləri nəzərdən keçirilir. Bu məqsədlə Bakı şəhərində yerləşən mənzillərin əsas xarakteristikalarını əhatə edən 500 müşahidədən ibarət sintetik məlumat bazası formalaşdırılır. Məlumatların emalı, modellərin qurulması və nəticələrin müqayisəli təhlili MATLAB R2023b proqram mühitində həyata keçirilmişdir.Modellərin proqnozlaşdırma keyfiyyətinin qiymətləndirilməsində orta mütləq xəta (MAE), orta kvadratik xəta (RMSE) və determinasiya əmsalı (R^2) göstəricilərindən istifadə edilir. Tədqiqatın məqsədi daşınmaz əmlakın kütləvi qiymətləndirilməsində müxtəlif alqoritmlərin tətbiq imkanlarını müəyyənləşdirmək və onların nəticələrinin müqayisəli qiymətləndirilməsidir.
Açar sözlər: daşınmaz əmlak, kütləvi qiymətləndirmə, hedonik reqressiya, Random Forest, Gradient Boosting, maşın öyrənməsi, MATLAB.

METHODS AND ALGORITHMS FOR MASS APPRAISAL OF REAL ESTATE

Abstract: The article examines the theoretical and methodological foundations of mass real estate appraisal and analyzes the applicability of modern mathematical models and machine learning algorithms in determining the market value of residential properties. The study considers the application of Hedonic Regression, Random Forest, and Gradient Boosting methods in the appraisal process. For this purpose, a synthetic dataset consisting of 500 observations and covering the main characteristics of residential properties located in Baku is developed. Data processing, model development, and comparative analysis of the results are intended to be carried out using the MATLAB R2023b software environment. The predictive performance of the models is evaluated using Mean Absolute Error (MAE), Root Mean Squared Error (RMSE), and the coefficient of determination (R^2). The aim of the study is to identify the applicability of different algorithms in mass real estate appraisal and to conduct a comparative evaluation of their performance.
Keywords: real estate, mass appraisal, hedonic regression, Random Forest, Gradient Boosting, machine learning, MATLAB.

GİRİŞ:Müasir dövrdə daşınmaz əmlak bazarının inkişafı, şəhərsalma proseslərinin genişlənməsi və mənzil fondunun strukturunda baş verən dəyişikliklər əmlak obyektlərinin bazar dəyərinin düzgün müəyyən edilməsini mühüm iqtisadi məsələlərdən birinə çevirmişdir. Mənzillərin qiymətinə yerləşmə mövqeyi, ümumi sahəsi, otaqların sayı, binanın texniki vəziyyəti, tikinti ili və nəqliyyat infrastrukturuna yaxınlıq kimi müxtəlif amillər təsir göstərir. Bu amillərin qarşılıqlı əlaqəsi

qiymətləndirmə prosesini mürəkkəbləşdirir və çoxsaylı daşınmaz əmlak obyektlərinin eyni metodoloji yanaşma əsasında qiymətləndirilməsini zəruri edir.

Daşınmaz əmlakın kütləvi qiymətləndirilməsi çoxsaylı obyektlərin dəyərinin vahid məlumat bazası, statistik üsullar və riyazi modellər əsasında müəyyən edilməsinə imkan verən sistemli yanaşmadır. Bu prosesdə hedonik reqressiya modeli əmlakın qiyməti ilə onun əsas xarakteristikaları arasındakı əlaqələrin müəyyənləşdirilməsi üçün geniş tətbiq olunur. Bununla yanaşı, maşın öyrənməsi metodlarının inkişafı Random Forest və Gradient Boosting kimi alqoritmlərin qiymətləndirmə prosesinə tətbiqi imkanlarını genişləndirmişdir. Bu alqoritmlər çoxsaylı dəyişənlər arasındakı mürəkkəb asılılıqların öyrənilməsi və qiymət proqnozlarının formalaşdırılması baxımından əhəmiyyət kəsb edir.

Daşınmaz əmlakın qiymətləndirilməsində müxtəlif modellərin nəticələrinin müqayisəsi onların proqnozlaşdırma dəqiqliyinin və tətbiq imkanlarının müəyyən edilməsi üçün mühüm əhəmiyyət daşıyır. Bu baxımdan məlumatların statistik təhlili, modellərin qurulması və nəticələrin qiymətləndirilməsi prosesində MATLAB proqram mühitindən istifadə məqsədəuyğun hesab olunur. Tədqiqatda Bakı şəhərində yerləşən mənzillərin əsas göstəricilərini əhatə edən sintetik məlumat bazası əsasında hedonik reqressiya, Random Forest və Gradient Boosting alqoritmlərinin müqayisəli təhlilinin aparılmışdır.

Daşınmaz əmlakın kütləvi qiymətləndirilməsinin mahiyyəti və əsas prinsipləri

Daşınmaz əmlakın kütləvi qiymətləndirilməsi çoxsaylı əmlak obyektlərinin dəyərinin vahid metodoloji yanaşma, statistik məlumatlar və riyazi modellər əsasında müəyyən edilməsini nəzərdə tutan qiymətləndirmə prosesidir. Fərdi qiymətləndirmədən fərqli olaraq, bu yanaşmada hər bir obyektin ayrıca və uzunmüddətli araşdırılması əvəzinə, oxşar xüsusiyyətlərə malik əmlak qrupları üzrə ümumi qanunauyğunluqlar müəyyən edilir. Bu, xüsusilə böyük şəhərlərdə yerləşən mənzil fondunun, torpaq sahələrinin və digər daşınmaz əmlak obyektlərinin qiymətləndirilməsi zamanı mühüm əhəmiyyət daşıyır[1].

Kütləvi qiymətləndirmənin əsas məqsədi daşınmaz əmlakın bazar dəyərini obyektiv göstəricilər əsasında müəyyən etmək, qiymətləndirmə prosesində subyektiv yanaşmanın təsirini azaltmaq və nəticələrin müqayisə edilə bilməsini təmin etməkdir. Bu metoddan əmlak vergitutmasının təşkili, dövlət və bələdiyyə əmlakının idarə edilməsi, investisiya qərarlarının qəbul edilməsi, ipoteka əməliyyatları və şəhərsalma planlaşdırılması kimi müxtəlif sahələrdə istifadə olunur.Daşınmaz əmlakın dəyəri bir sıra fiziki, iqtisadi və coğrafi amillərin qarşılıqlı təsiri nəticəsində formalaşır. Mənzilin ümumi sahəsi, otaqların sayı, yerləşdiyi mərtəbə, binanın tikinti ili, təmir vəziyyəti, nəqliyyat infrastrukturuna yaxınlığı və şəhər mərkəzinə olan məsafəsi qiymətə təsir göstərən əsas göstəricilər sırasındadır. Bu amillərin hər biri əmlakın bazar cəlbediciliyinə müxtəlif səviyyədə təsir edir. Buna görə də kütləvi qiymətləndirmə zamanı yalnız bir göstəriciyə əsaslanmaq deyil, bütün əhəmiyyətli parametrlərin birgə təhlilini aparmaq tələb olunur[2].

Kütləvi qiymətləndirmə prosesinin etibarlılığı ilk növbədə istifadə edilən məlumatların keyfiyyətindən asılıdır. Məlumat bazasında qiymətləndirilən obyektlərin xüsusiyyətləri düzgün və ardıcıl şəkildə əks etdirilməli, çatışmayan və uyğunsuz göstəricilər müəyyənləşdirilməlidir. Eyni zamanda, məlumatların müqayisə edilə bilən formatda təqdim olunması və qiymətə təsir edən amillərin düzgün seçilməsi modellərin proqnozlaşdırma qabiliyyətinə birbaşa təsir göstərir.Kütləvi qiymətləndirmənin əsas prinsiplərindən biri vahid yanaşmanın tətbiqidir. Bu prinsipə əsasən, oxşar xüsusiyyətlərə malik obyektlər eyni qiymətləndirmə meyarları və metodoloji qaydalar əsasında təhlil edilməlidir. Digər mühüm prinsip məlumatların obyektivliyi və nəticələrin yoxlanıla bilməsidir. Qiymətləndirmə modeli real bazar münasibətlərini mümkün qədər düzgün əks etdirməli, əldə edilən nəticələr isə statistik göstəricilər vasitəsilə qiymətləndirilməlidir. Müasir şəraitdə kütləvi qiymətləndirmə prosesinin avtomatlaşdırılması və kompüter modellərindən istifadə edilməsi xüsusi əhəmiyyət kəsb edir. Statistik reqressiya modelləri və maşın öyrənməsi alqoritmləri çoxsaylı göstəricilər arasındakı əlaqələrin müəyyən edilməsinə, qiymət dəyişikliklərinin

təhlilinə və proqnozlaşdırma prosesinin təkmilləşdirilməsinə imkan verir. Bu baxımdan hedonik reqressiya, Random Forest və Gradient Boosting metodları daşınmaz əmlakın qiymətləndirilməsi üçün tətbiq oluna bilən əsas yanaşmalar hesab edilir.

Beləliklə, daşınmaz əmlakın kütləvi qiymətləndirilməsi məlumatların sistemləşdirilməsi, qiymətə təsir edən amillərin müəyyənləşdirilməsi, uyğun riyazi modelin seçilməsi və nəticələrin statistik qiymətləndirilməsi mərhələlərindən ibarət kompleks prosesdir. Bu mərhələlərin ardıcıl və düzgün təşkili daşınmaz əmlak bazarının təhlili və qiymətlərin proqnozlaşdırılması üçün etibarlı metodoloji əsas yaradır[13].

Daşınmaz əmlakın dəyərinə təsir edən əsas amillər və onların riyazi modelləşdirilməsi

Daşınmaz əmlakın bazar qiyməti bir sıra fiziki, məkan və keyfiyyət göstəricilərinin qarşılıqlı təsiri nəticəsində formalaşır. Kütləvi qiymətləndirmə prosesində bu göstəricilərin düzgün müəyyənləşdirilməsi, sistemləşdirilməsi və riyazi dəyişənlər şəklində ifadə olunması qiymətləndirmə modellərinin etibarlılığını təmin edən əsas şərtlərdəndir. Mənzillərin bazar dəyərinin müəyyən edilməsində yalnız onların fiziki xüsusiyyətləri deyil, həmçinin yerləşmə mövqeyi, nəqliyyat əlçatanlığı və texniki vəziyyəti də nəzərə alınmalıdır[12].

Tədqiqat çərçivəsində daşınmaz əmlakın qiymətinə təsir edən amillər üç əsas qrupa bölünür:

1. Fiziki göstəricilər:
   - S – mənzilin ümumi sahəsi (m^2);
   - R – otaqların sayı;
   - Y – binanın tikinti ili;
   - F – mənzilin yerləşdiyi mərtəbə;
   - N – binanın ümumi mərtəbə sayı.
2. Məkan göstəriciləri:
   - Dm – metro stansiyasına olan məsafə (km);
   - Dc – şəhər mərkəzinə olan məsafə (km);
   - L – mənzilin yerləşdiyi rayon.
3. Keyfiyyət göstəriciləri:
   - Q – mənzilin təmir vəziyyəti;
   - B – binanın növü.

Sadalanan göstəricilərdən asılı dəyişən kimi mənzilin bazar qiyməti (P) qəbul edilir. Bu göstəricilərin qarşılıqlı əlaqəsi daşınmaz əmlakın qiymətinin formalaşmasını izah edən funksional model vasitəsilə ifadə oluna bilər[7].

$$P = f(S, R, Y, F, N, Dm, Dc, L, Q, B) \quad (1)$$

Burada P – mənzilin bazar qiymətini, f isə qiymətin müstəqil dəyişənlərdən asılılığını ifadə edən funksiyanı göstərir.

Dəyişənlərin riyazi modelə hazırlanması

Riyazi modelin qurulması zamanı göstəricilərin kəmiyyət və keyfiyyət xarakteri nəzərə alınmalıdır. Mənzilin sahəsi, otaqların sayı, tikinti ili, mərtəbəsi və məsafə göstəriciləri kəmiyyət dəyişənləridir. Rayon, təmir vəziyyəti və binanın növü isə kateqorik dəyişənlər hesab olunur.

Kateqorik göstəricilərin reqressiya modelinə daxil edilməsi üçün indikator dəyişənlərdən istifadə edilir. İndikator dəyişənlər müəyyən kateqoriyanın mövcudluğunu 1, digər kateqoriyaya aid olmanı isə 0 qiyməti ilə ifadə edir[8].

Məsələn, mənzilin təmir vəziyyətinin üç kateqoriyadan ibarət olduğunu qəbul edək:

$Q_1 = 1$ – təmirli mənzil; $Q_2 = 1$ – orta təmirli mənzil; $Q_3 = 1$ – təmirsiz mənzil.

Hər bir mənzil üçün bu göstəricilərdən yalnız biri 1, digər ikisi isə 0 qiymətini alır. Lakin reqressiya modelində mükəmməl xətti asılılığın yaranmasının qarşısını almaq üçün üç indikator dəyişəndən yalnız ikisi modelə daxil edilir. Üçüncü kateqoriya istinad kateqoriyası kimi qəbul olunur.

Eyni qayda rayon və binanın növü göstəricilərinə də tətbiq edilir. Belə yanaşma kateqoriyalar arasında süni kəmiyyət ardıcıllığının yaranmasının qarşısını alır və modelin statistik baxımdan düzgün qurulmasına imkan verir.

Hedonik reqressiya modelinin qurulması.Daşınmaz əmlakın qiymətinə təsir edən amillərin kəmiyyət baxımından qiymətləndirilməsi üçün hedonik reqressiya modelindən istifadə olunur. Bu model əmlakın bazar qiymətini onun ayrı-ayrı xüsusiyyətlərinin funksiyası kimi təqdim edir. Tədqiqatda istifadə ediləcək modelin ümumi xətti forması aşağıdakı kimi ifadə olunur:

$$P_i = \beta_0 + \beta_1 S_i + \beta_2 R_i + \beta_3 Y_i + \beta_4 F_i + \beta_5 N_i + \beta_6 Dm_i + \beta_7 Dc_i + \Sigma\beta_{8j} L_{ij} + \Sigma\beta_{9k} Q_{ik} + \Sigma\beta_{10m} B_{im} + \varepsilon_i \quad (2)$$

P_i – i-ci mənzilin bazar qiyməti;

β_0 – modelin sərbəst həddi;

$\beta_1, \beta_2, \ldots, \beta_7$ – kəmiyyət dəyişənlərinə uyğun reqressiya əmsalları;

β_{8j} – rayon indikatorlarının reqressiya əmsalları;

β_{9k} – təmir vəziyyəti indikatorlarının reqressiya əmsalları;

β_{10m} – binanın növü indikatorlarının reqressiya əmsalları;

L_{ij}, Q_{ik}, B_{im} – müvafiq kateqoriyaları ifadə edən indikator dəyişənlər;

ε_i – modelin təsadüfi xətası;

i – müşahidənin sıra nömrəsidir.

Burada j, k və m indeksləri müvafiq olaraq rayon, təmir vəziyyəti və bina növü kateqoriyalarını göstərir. Hər bir kateqorik göstərici üzrə bir kateqoriya istinad kateqoriyası kimi modeldən kənarda saxlanılır[3].

Reqressiya əmsalları digər göstəricilər sabit qaldıqda müvafiq dəyişənin mənzilin qiymətinə təsirini xarakterizə edir. Məsələn, β_1 əmsalı mənzilin ümumi sahəsi bir kvadratmetr artdıqda qiymətdə baş verən orta dəyişməni göstərir. Kateqorik dəyişənlərin əmsalları isə müvafiq kateqoriyanın istinad kateqoriyası ilə müqayisədə qiymət fərqini ifadə edir.

Model parametrlərinin ən kiçik kvadratlar metodu ilə qiymətləndirilməsi

Hedonik reqressiya modelinin parametrlərinin müəyyənləşdirilməsində ən kiçik kvadratlar metodundan istifadə edilir. Bu metod faktiki qiymətlərlə model tərəfindən proqnozlaşdırılan qiymətlər arasındakı fərqlərin kvadratları cəminin minimumlaşdırılmasına əsaslanır.

Metodun məqsəd funksiyası aşağıdakı kimi ifadə olunur:

$$SSE = \Sigma(i=1\text{-dən } n\text{-ə}) (P_i - \hat{P}_i)^2 \rightarrow \min \quad (3)$$

Burada:

SSE – kvadrat xətaların cəmi;

P_i – mənzilin faktiki bazar qiyməti;

$\hat{P}_i$ – model tərəfindən proqnozlaşdırılan qiymət;

n – müşahidələrin ümumi sayıdır.

Ən kiçik kvadratlar metodunun matris formasında ifadəsi aşağıdakı kimidir:

$$\hat{\beta} = (X^T X)^{-1} X^T P \quad (4)$$

Burada:

$\hat{\beta}$ – reqressiya əmsallarının qiymətləndirilmiş vektoru;

X – müstəqil dəyişənlərdən və sərbəst hədd sütunundan ibarət dizayn matrisi;

X^T – X matrisinin transpozisi;

$(X^T X)^{-1}$ – müvafiq matrisin tərs matrisi;

P – mənzillərin faktiki qiymətlərini əks etdirən vektordur.

Bu düstur $X^T X$ matrisinin tərsinin mövcud olduğu hallarda tətbiq edilir. Praktiki hesablamalarda MATLAB proqram mühitində matrisin tərsini birbaşa hesablamaq əvəzinə, ədədi baxımdan daha dayanıqlı həll üsullarından istifadə edilməsi məqsədəuyğundur.

Məlumat bazasının formalaşdırılması və ilkin emal ardıcıllığı

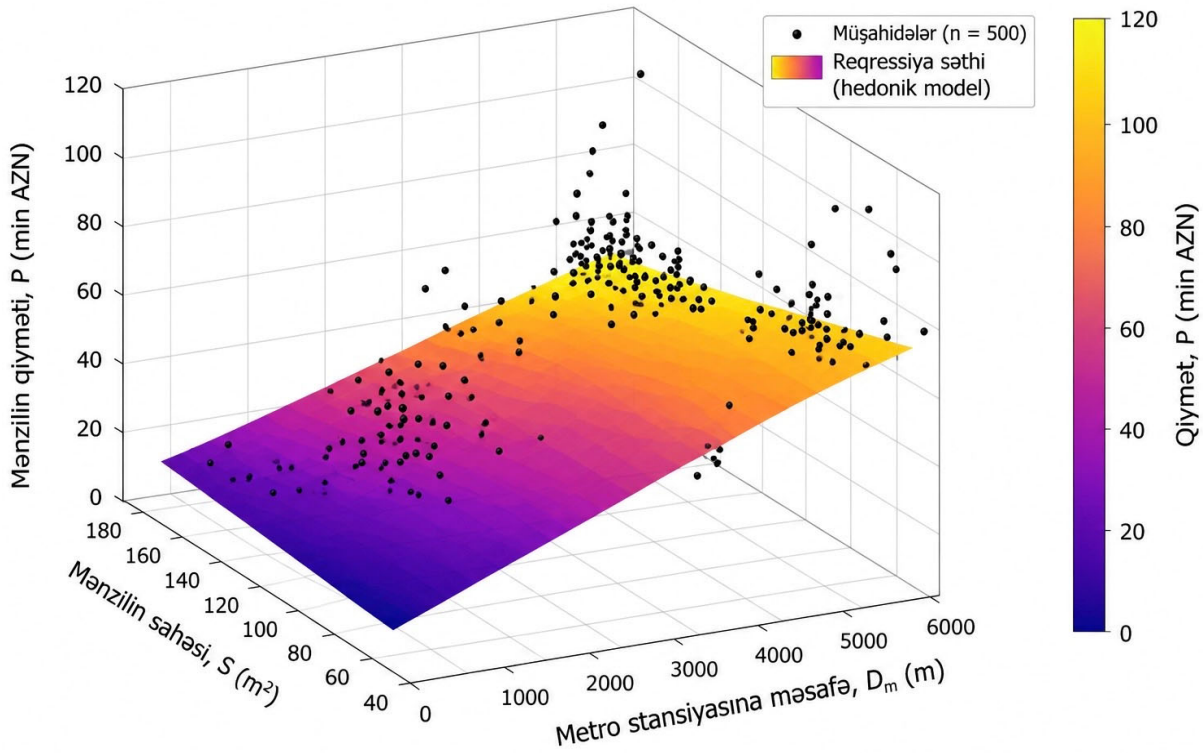
Tədqiqatda Bakı şəhərində yerləşən mənzillərin əsas xarakteristikalarını əhatə edən 500 sintetik müşahidədən ibarət məlumat bazasından istifadə edilməsi nəzərdə tutulur. Hər bir müşahidə

ayrıca mənzili, məlumat bazasının sütunları isə həmin mənzilin fiziki, məkan və keyfiyyət göstəricilərini əks etdirir.

Məlumatların modelləşdirməyə hazırlanması aşağıdakı ardıcıllıqla həyata keçirilir:

1. Məlumat bazasının formalaşdırılması;
2. Qiymətə təsir edən göstəricilərin seçilməsi;
3. Məlumatların yoxlanılması və ilkin emalı;
4. Kateqorik dəyişənlərin indikator dəyişənlərə çevrilməsi;
5. Məlumatların təlim və test seçmələrinə ayrılması;
6. Riyazi modellərin qurulması və qiymətləndirilməsi.

Beləliklə, daşınmaz əmlakın qiymətinə təsir edən göstəricilərin sistemləşdirilməsi və riyazi model şəklində təqdim edilməsi kütləvi qiymətləndirmənin metodoloji əsasını təşkil edir. Seçilmiş dəyişənlər və qurulmuş hedonik reqressiya modeli sonrakı mərhələdə Random Forest və Gradient Boosting alqoritmlərinin eyni məlumat bazası əsasında tətbiqi və müqayisəli təhlili üçün əsas yaradır.



Şəkil 1. Daşınmaz əmlak qiymətlərinin sahə və metroya məsafədən asılılığının modelləşdirilməsi.

Şəkildə daşınmaz əmlakın qiymətinin mənzilin sahəsi və metro stansiyasına olan məsafədən asılılığı üçölçülü qrafik formasında təsvir edilmişdir. Modelləşdirmə üçün Bakı şəhərində yerləşən mənzilləri xarakterizə edən 500 müşahidədən ibarət sintetik məlumat bazasının formalaşdırılması nəzərdə tutulmuşdur. Qrafikdə mənzilin sahəsi 40–180 m², metro stansiyasına məsafə isə 0–6000 m intervalında göstərilmişdir. Qiymət göstəriciləri min manatla ifadə edilmişdir. Qara nöqtələr ayrı-ayrı müşahidələri, rəngli səth isə hedonik reqressiya modeli əsasında hesablanan proqnoz qiymətlərini əks etdirir. Bu nəticələrin əldə edilməsi üçün ilkin məlumatların formalaşdırılması, dəyişənlərin seçilməsi və reqressiya modelinin qurulması mərhələləri nəzərdə tutulur. Beləliklə, qrafik mənzilin sahəsi artdıqca qiymətin yüksəlməsi, metrodan məsafə artdıqca isə digər şərtlər sabit qalmaqla qiymətin dəyişməsi meylini vizual şəkildə nümayiş etdirir[11].

Random Forest alqoritminin nəzəri və riyazi əsasları

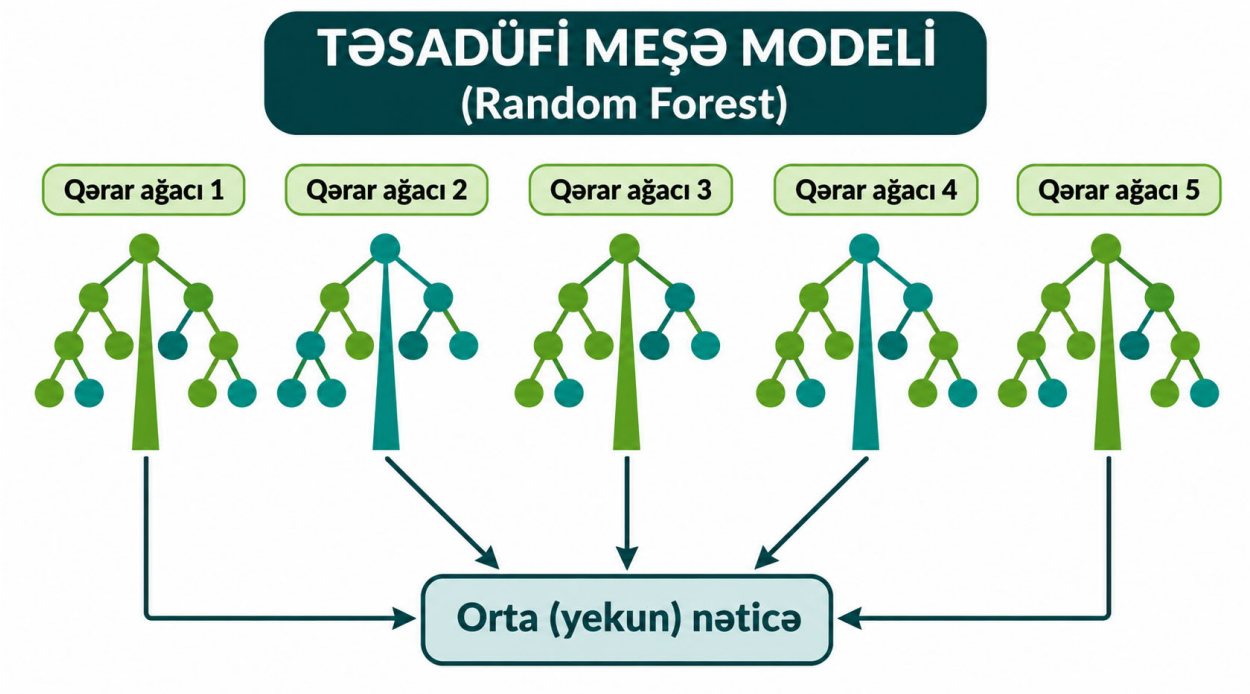
Daşınmaz əmlakın kütləvi qiymətləndirilməsi prosesində qiymətə təsir edən amillər arasında mürəkkəb və qeyri-xətti asılılıqların mövcudluğu ənənəvi reqressiya modellərinin tətbiqini

müəyyən hallarda məhdudlaşdıra bilər. Bu baxımdan maşın öyrənməsi metodlarından biri olan Random Forest alqoritmi çoxsaylı göstəricilər arasındakı əlaqələrin müəyyənləşdirilməsi və qiymət proqnozlarının formalaşdırılması üçün əlverişli yanaşma hesab olunur.

Random Forest (Təsadüfi Meşə) çoxsaylı qərar ağaclarının birləşdirilməsi əsasında fəaliyyət göstərən ansambl öyrənmə alqoritmidir. Metodun əsas xüsusiyyəti müxtəlif seçmələr əsasında qurulan qərar ağaclarının nəticələrini birləşdirərək daha sabit və ümumiləşdirilmiş proqnoz əldə edilməsidir. Hər bir qərar ağacı məlumatların təsadüfi seçilmiş alt çoxluğu və giriş dəyişənlərinin müəyyən kombinasiyası əsasında formalaşdırılır.

Random Forest alqoritminin işləmə prinsipi aşağıdakı ardıcıllıqla həyata keçirilir:

1. İlkin məlumat bazasından təsadüfi seçmə üsulu ilə bir neçə alt məlumat çoxluğu yaradılır.
2. Hər bir alt çoxluq əsasında ayrıca qərar ağacı qurulur.
3. Qərar ağaclarının budaqlanması zamanı giriş göstəricilərinin təsadüfi seçilmiş alt qrupu nəzərdən keçirilir.
4. Hər bir ağac müstəqil şəkildə proqnoz qiyməti formalaşdırır.
5. Reqressiya məsələsində bütün ağacların proqnozlarının ədədi ortası hesablanır.
6. Alınmış orta qiymət modelin yekun proqnozu kimi qəbul edilir.



Şəkil 2. Random Forest alqoritminin iş prinsipi.

Şəkil 2-də Random Forest alqoritminin əsas iş prinsipi təsvir edilmişdir. Sxemdən göründüyü kimi, ilkin məlumatlar əsasında müxtəlif qərar ağacları formalaşdırılır və hər bir ağac müstəqil şəkildə proqnoz nəticəsi əldə edir. Reqressiya məsələsində ayrı-ayrı ağacların verdiyi qiymətlər ədədi orta üsulu ilə birləşdirilərək yekun proqnoz müəyyən edilir. Bu yanaşma ayrı-ayrı qərar ağaclarının nəticələrində yaranan dəyişkənliyin azaldılmasına və daha sabit qiymətləndirmə nəticəsinin əldə edilməsinə imkan verir[16].

Random Forest modelinin ümumi riyazi ifadəsi aşağıdakı kimidir:

$$\hat{P}_RF(X) = (1/M) \times \Sigma\ T_m(X),\ m = 1, 2, \ldots, M \quad (5)$$

Burada:

M – qurulan qərar ağaclarının ümumi sayı;

T_m(X) – m-ci qərar ağacının X giriş göstəriciləri əsasında verdiyi proqnoz;

X – daşınmaz əmlak obyektinin xarakteristikalarını əks etdirən giriş dəyişənləri;
$\hat{P}_RF(X)$ – Random Forest modelinin yekun qiymət proqnozudur.
Tədqiqatda mənzillərin qiymətləndirilməsi üçün 500 müşahidədən ibarət sintetik məlumat bazasından istifadə edilir. Məlumat bazasında mənzilin sahəsi, otaqların sayı, tikinti ili, mərtəbəsi, binanın ümumi mərtəbə sayı, metroya və şəhər mərkəzinə məsafə, yerləşdiyi rayon, təmir vəziyyəti və bina növü əsas giriş dəyişənləri kimi qəbul olunur.
Random Forest alqoritminin hesablama prinsipini izah etmək üçün bir mənzil üzrə beş qərar ağacının aşağıdakı proqnoz qiymətlərini verdiyini fərz edək:
$T_1(X)$ = 145 000 AZN;
$T_2(X)$ = 148 000 AZN;
$T_3(X)$ = 142 000 AZN;
$T_4(X)$ = 150 000 AZN;
$T_5(X)$ = 145 000 AZN.
Bu halda yekun proqnoz aşağıdakı kimi hesablanır:
$\hat{P}_RF(X) = (145000 + 148000 + 142000 + 150000 + 145000) / 5$
$\hat{P}_RF(X) = 730000 / 5$

$$\hat{P}_RF(X) = 146000 \text{ AZN} \quad (6)$$

Beləliklə, beş qərar ağacının proqnozlarının birləşdirilməsi nəticəsində mənzilin hesablanmış qiyməti 146 000 AZN təşkil edir. Bu rəqəm alqoritmin işləmə mexanizmini göstərən şərti hesablama nümunəsidir və eksperimental nəticə kimi qəbul edilmir.
Random Forest metodunun mühüm üstünlüklərindən biri ayrı-ayrı qərar ağaclarının proqnozlarında yaranan dəyişkənliyin ümumi nəticəyə təsirini azaltmasıdır. Eyni zamanda, alqoritm müxtəlif tipli giriş göstəricilərini emal edə, qeyri-xətti əlaqələri müəyyənləşdirə və çoxsaylı dəyişənlərin qarşılıqlı təsirini nəzərə ala bilir. Bu xüsusiyyətlər onun daşınmaz əmlakın kütləvi qiymətləndirilməsi məsələlərində tətbiqini məqsədəuyğun edir[13].
Gradient Boosting alqoritminin nəzəri və riyazi əsasları
Gradient Boosting daşınmaz əmlakın qiymətinin proqnozlaşdırılması üçün istifadə edilən digər ansambl maşın öyrənməsi metodudur. Random Forest alqoritmindən fərqli olaraq, bu yanaşmada qərar ağacları paralel və müstəqil şəkildə deyil, ardıcıl mərhələlərlə qurulur. Hər yeni ağac əvvəlki mərhələdə əldə edilmiş proqnozların xətalarını azaltmağa istiqamətləndirilir.
Gradient Boosting metodunun əsas ideyası ilkin proqnoz modelinin yaradılması və sonrakı mərhələlərdə həmin modelin nəticələrinin tədricən yaxşılaşdırılmasıdır. Alqoritm əvvəlki proqnozla faktiki qiymətlər arasındakı fərqləri müəyyən edir və növbəti qərar ağacını həmin fərqlərin azaldılması istiqamətində öyrədir.
Alqoritmin ümumi hesablama ardıcıllığı aşağıdakı kimidir:

1. İlkin proqnoz qiyməti müəyyən edilir.
2. Faktiki qiymətlərlə proqnozlaşdırılmış qiymətlər arasındakı fərq hesablanır.
3. Mövcud xətaları izah edən yeni qərar ağacı qurulur.
4. Yeni ağacın nəticəsi əvvəlki modelə müəyyən əmsalla əlavə edilir.
5. Proses müəyyən edilmiş iterasiya sayına qədər təkrarlanır.
6. Son mərhələdə bütün ağacların nəticələrini birləşdirən yekun proqnoz əldə edilir.

Gradient Boosting modelinin ümumi riyazi ifadəsi aşağıdakı kimi təqdim olunur:

$$F_{m(X)} = F_(m-1)(X) + \eta \times h_m(X) \quad (7)$$

Burada:
$F_m(X)$ – m-ci mərhələdə formalaşan yekun proqnoz;
$F_(m-1)(X)$ – əvvəlki mərhələnin proqnozu;
$h_m(X)$ – m-ci mərhələdə qurulan yeni qərar ağacının nəticəsi;
η – öyrənmə sürətini ifadə edən əmsaldır.

Modelin optimallaşdırılması zamanı faktiki və proqnozlaşdırılan qiymətlər arasındakı fərqlərin kvadratları cəmi minimumlaşdırılır:

$$J(F) = \Sigma(P_i - F(X_i))^2 \rightarrow \min \quad (8)$$

Burada:

J(F) – modelin məqsəd funksiyası;

P_i – i-ci mənzilin faktiki qiyməti;

F(X_i) – modelin həmin mənzil üçün hesabladığı proqnoz qiyməti;

n – müşahidələrin sayıdır.

Gradient Boosting alqoritmində hər yeni mərhələnin qurulması zamanı əvvəlki modelin qalıq xətaları nəzərə alınır. Kvadratik xəta funksiyası üçün bu qalıqlar aşağıdakı kimi ifadə olunur:

$$r_i = P_i - F_(m-1)(X_i) \quad (9)$$

Burada r_i əvvəlki mərhələdə i-ci müşahidə üzrə yaranmış proqnoz fərqini göstərir. Yeni qərar ağacı həmin fərqləri öyrənərək modelin növbəti mərhələdə təkmilləşdirilməsinə xidmət edir.

Məsələn, hər hansı mənzil üçün ilkin modelin proqnozu 130 000 AZN, faktiki qiymət isə 150 000 AZN olarsa, ilkin proqnoz xətası aşağıdakı kimi hesablanır:

r = 150000 - 130000 = 20000 AZN.

Əgər növbəti qərar ağacı bu xəta üzrə 15 000 AZN düzəliş müəyyən edərsə və öyrənmə sürəti η = 0,1 qəbul olunarsa, yeni proqnoz belə hesablanır:

$F_1(X) = 130000 + 0{,}1 \times 15000$

$$F_1(X) = 131500 \text{ AZN} \quad (10)$$

Beləliklə, yeni mərhələdə proqnozlaşdırılan qiymət 130 000 AZN-dən 131 500 AZN-ə yüksəlir və ilkin proqnozla faktiki qiymət arasındakı fərq azalır. Bu nümunə Gradient Boosting metodunun mərhələli öyrənmə mexanizmini izah edir.

Gradient Boosting alqoritminin əsas üstünlüyü mürəkkəb qeyri-xətti asılılıqları öyrənmək və əvvəlki mərhələlərdə yaranmış xətaları ardıcıl şəkildə azaltmaq imkanına malik olmasıdır. Bununla yanaşı, öyrənmə sürətinin və qərar ağaclarının sayının düzgün seçilməsi mühüm əhəmiyyət daşıyır. Parametrlərin uyğun seçilməməsi modelin həddindən artıq öyrənməsinə və yeni məlumatlar üzrə proqnozlaşdırma qabiliyyətinin zəifləməsinə səbəb ola bilər[6]. *Random Forest və Gradient Boosting metodlarının müqayisəli xüsusiyyətləri*

Hər iki alqoritm qərar ağacları əsasında qurulsa da, onların öyrənmə mexanizmləri və proqnozların formalaşdırılması prinsipləri fərqlənir. Random Forest müxtəlif qərar ağaclarının nəticələrini birləşdirərək yekun qiymət əldə edir. Gradient Boosting isə ardıcıl qurulan ağaclar vasitəsilə əvvəlki mərhələlərin proqnoz xətalarını azaltmağa çalışır.Random Forest modelində yekun nəticə ağacların proqnozlarının orta qiyməti əsasında formalaşdığı halda, Gradient Boosting modelində hər yeni ağac əvvəlki modelin nəticəsinə müəyyən düzəliş əlavə edir. Bu fərq onların hesablama sürətinə, modelin sabitliyinə və proqnozlaşdırma keyfiyyətinə təsir göstərə bilər. Daşınmaz əmlakın qiymətləndirilməsi baxımından hər iki metodun tətbiqi mənzilin fiziki, məkan və keyfiyyət göstəriciləri arasındakı mürəkkəb əlaqələrin öyrənilməsinə imkan verir. Bununla belə, hansı alqoritmin daha yüksək proqnozlaşdırma dəqiqliyinə malik olduğunu əvvəlcədən müəyyən etmək düzgün deyil. Bu məsələ eyni məlumat bazası və eyni test seçməsi əsasında aparılan eksperimental hesablamaların nəticələrinə görə müəyyən edilməlidir.

Beləliklə, Random Forest və Gradient Boosting alqoritmlərinin riyazi və metodoloji xüsusiyyətlərinin araşdırılması onların hedonik reqressiya modeli ilə müqayisəli qiymətləndirilməsi üçün nəzəri əsas yaradır[7].

Eksperimental tədqiqatın təşkili və məlumat bazasının hazırlanması

Nəzəri olaraq araşdırılmış modellərin tətbiq imkanlarını qiymətləndirmək məqsədilə MATLAB R2023b proqram mühitində eksperimental tədqiqat aparılmışdır. Tədqiqat üçün Bakı şəhərində yerləşən mənzillərin əsas fiziki, məkan və keyfiyyət göstəricilərini əhatə edən 500 müşahidədən ibarət sintetik məlumat bazası yaradılmışdır. Qeyd etmək lazımdır ki, istifadə edilən məlumatlar

real daşınmaz əmlak elanlarından və ya rəsmi bazar statistikasından götürülməmiş, modellərin qurulması və müqayisəsi məqsədilə süni şəkildə formalaşdırılmışdır. Məlumat bazasına mənzilin ümumi sahəsi, otaqların sayı, binanın tikinti ili, mənzilin yerləşdiyi mərtəbə, binanın ümumi mərtəbə sayı, metro stansiyasına və şəhər mərkəzinə olan məsafə, yerləşdiyi rayon, təmir vəziyyəti və binanın növü daxil edilmişdir. Asılı dəyişən kimi mənzilin qiyməti (AZN) qəbul olunmuşdur. Sintetik qiymət göstəricisinin formalaşdırılmasında mənzilin sahəsi və digər xarakteristikaları ilə yanaşı, təsadüfi xəta komponenti də nəzərə alınmışdır. Modellərin obyektiv müqayisəsini təmin etmək üçün məlumat bazası təlim və test seçmələrinə ayrılmışdır. Ümumi 500 müşahidənin 80%-ni təşkil edən 400 müşahidə modellərin öyrədilməsi, qalan 20%-ni təşkil edən 100 müşahidə isə test məqsədilə istifadə edilmişdir. Təsadüfi seçmənin təkrarlana bilməsi üçün MATLAB mühitində təsadüfi ədədlər generatorunun başlanğıc vəziyyəti sabitləşdirilmişdir. Beləliklə, hər üç model eyni təlim və test müşahidələri əsasında qiymətləndirilmişdir. Eksperiment çərçivəsində üç qiymətləndirmə modeli tətbiq edilmişdir: hedonik xətti reqressiya, Random Forest və Gradient Boosting. Hedonik reqressiya modeli fitlm funksiyası vasitəsilə qurulmuş, Random Forest alqoritmində 200 qərar ağacından istifadə edilmişdir. Gradient Boosting modeli isə LSBoost metodu əsasında 100 öyrənmə mərhələsi və 0,05 öyrənmə sürəti ilə formalaşdırılmışdır. Modellərin parametrləri onların test seçməsində proqnozlaşdırma nəticələrinin müqayisə edilməsi məqsədilə müəyyən edilmişdir[14].

Modellərin proqnozlaşdırma keyfiyyətinin qiymətləndirilməsi

Modellərin nəticələrinin müqayisəsi üçün orta mütləq xəta (MAE), orta kvadratik xətanın kvadrat kökü (RMSE) və determinasiya əmsalı (R^2) göstəricilərindən istifadə edilmişdir. Bu meyarlar faktiki qiymətlərlə modellərin hesabladığı proqnoz qiymətləri arasındakı fərqləri müxtəlif aspektlərdən qiymətləndirməyə imkan verir.

Orta mütləq xəta aşağıdakı düsturla hesablanır:

$$MAE = (1/n) \times \Sigma |P_i - \hat{P}_i| \quad (11)$$

Orta kvadratik xətanın kvadrat kökü isə aşağıdakı kimi ifadə olunur:

$$RMSE = \sqrt{[(1/n) \times \Sigma (P_i - \hat{P}_i)^2]} \quad (12)$$

Determinasiya əmsalı modelin asılı dəyişəndəki variasiyanı nə dərəcədə izah etdiyini göstərir:

$$R^2 = 1 - [\Sigma (P_i - \hat{P}_i)^2 / \Sigma (P_i - \bar{P})^2] \quad (13)$$

Burada n – test müşahidələrinin sayı, P_i – faktiki qiymət, $\hat{P}_i$ – modelin proqnozlaşdırdığı qiymət, $\bar{P}$ isə faktiki qiymətlərin orta qiymətidir. MAE və RMSE göstəricilərinin kiçik olması modelin proqnoz xətalarının az olduğunu göstərir. R^2 göstəricisinin 1-ə yaxınlaşması isə modelin məlumatlardakı dəyişkənliyi daha yaxşı izah etdiyini ifadə edir. Mənfi R^2 qiyməti modelin test seçməsində orta qiymətə əsaslanan sadə proqnozdan belə zəif nəticə göstərdiyini bildirir[13].

Eksperimental nəticələrin müqayisəli təhlili

MATLAB R2023b proqram mühitində aparılmış hesablamaların nəticələrinə əsasən, modellərin test seçməsində əldə etdiyi göstəricilər fərqlənmişdir. Hedonik reqressiya modeli MAE üzrə 12 104 AZN, RMSE üzrə 15 029 AZN və R^2 üzrə 0,8030 nəticəsi göstərmişdir. Bu göstəricilər modelin test məlumatlarında mənzil qiymətlərinin dəyişməsini nisbətən yüksək səviyyədə izah etdiyini nümayiş etdirir.Random Forest modelində MAE 30 258 AZN, RMSE 36 150 AZN, R^2 isə −0,1397 olmuşdur. Mənfi determinasiya əmsalı bu modelin istifadə edilmiş test seçməsində qənaətbəxş ümumiləşdirmə nəticəsi əldə etmədiyini göstərir. Gradient Boosting modelində isə MAE 28 518 AZN, RMSE 33 258 AZN və R^2 0,0354 təşkil etmişdir. Bu nəticə Random Forest modeli ilə müqayisədə müəyyən yaxşılaşma göstərsə də, hedonik reqressiya modelinin nəticələrindən xeyli aşağıdır.

Cədvəl 1. Modellərin test seçməsi üzrə müqayisəli qiymətləndirmə nəticələri

Qiymətləndirmə meyarı	Hedonic Regression	Random Forest	Gradient Boosting
MAE (AZN)	12 104	30 258	28 518
RMSE (AZN)	15 029	36 150	33 258
R^2	0,8030	−0,1397	0,0354

Cədvəl 1-dən göründüyü kimi, tədqiqatda istifadə edilmiş sintetik məlumat bazası və seçilmiş model parametrləri şəraitində ən yaxşı nəticə hedonik reqressiya modeli tərəfindən əldə edilmişdir. Random Forest və Gradient Boosting modellərində xəta göstəricilərinin daha yüksək olması onların bu eksperiment çərçivəsində test məlumatlarına uyğun proqnoz vermək imkanlarının məhdud olduğunu göstərir. Modellərin qiymətləndirmə göstəricilərinin vizual müqayisəsi Şəkil 3-də təqdim edilmişdir

Modellərin müqayisəli qiymətləndirilməsi aşağıdakı ardıcıllıqla aparılmışdır:

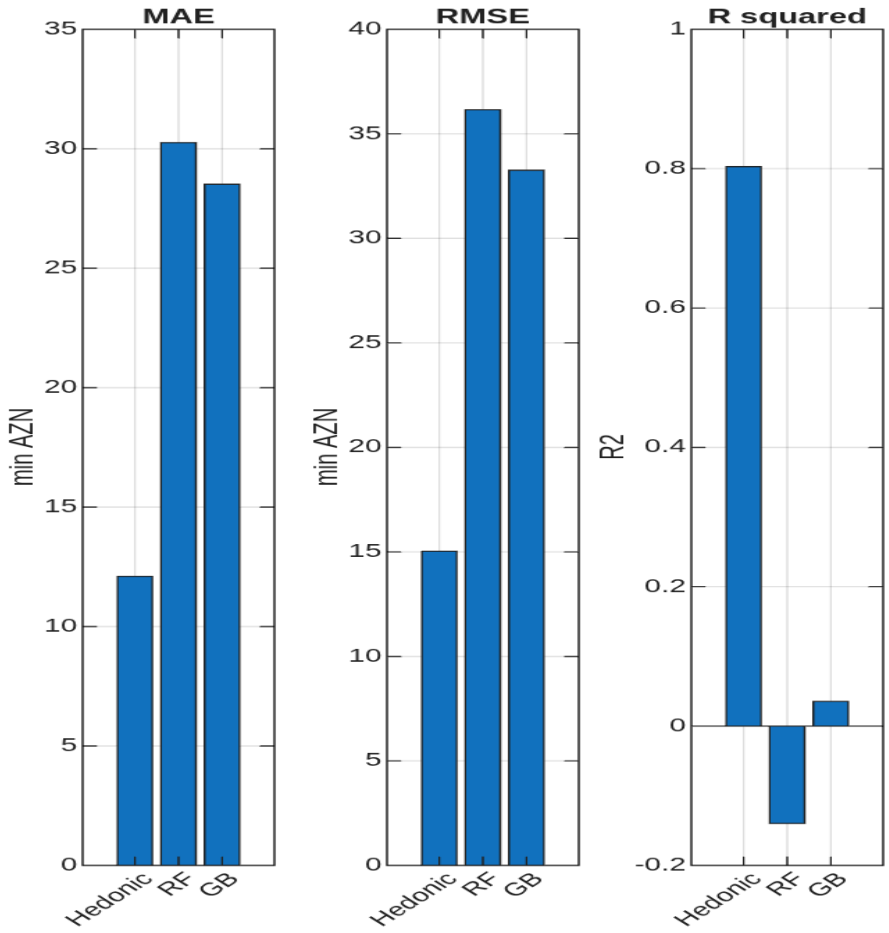
500 sintetik müşahidə → 400 təlim və 100 test məlumatı → 3 qiymətləndirmə modeli → MAE, RMSE və R^2 göstəriciləri → müqayisəli nəticələr.

Tətbiq edilmiş modellər:

Hedonic Regression | Random Forest | Gradient Boosting

Qiymətləndirmə meyarları:

MAE ↓ | RMSE ↓ | R^2 ↑



Şəkil 3. Daşınmaz əmlakın kütləvi qiymətləndirilməsi üzrə reqressiya modellərinin müqayisəsi.

Şəkil 3-də təqdim olunan qrafikdə daşınmaz əmlakın kütləvi qiymətləndirilməsi üçün tətbiq edilmiş Hedonic Regression, Random Forest və Gradient Boosting modellərinin test seçməsi üzrə nəticələri MAE, RMSE və R^2 göstəriciləri əsasında müqayisə edilmişdir. Qrafikdən aydın görünür ki, hedonik reqressiya modeli hər iki xəta meyarı üzrə digər alqoritmlərlə müqayisədə daha aşağı nəticə göstərmişdir. Belə ki, modelin MAE göstəricisi 12 104 AZN, RMSE göstəricisi isə 15 029 AZN təşkil etmişdir. Determinasiya əmsalının 0,8030 olması isə modelin test məlumatlarında mənzil qiymətlərindəki dəyişkənliyin təxminən 80,3%-ni izah etdiyini göstərir. Bu nəticələr hedonik reqressiya modelinin tədqiqatda istifadə olunan sintetik məlumat bazasının strukturuna daha yaxşı uyğunlaşdığını təsdiqləyir. Random Forest alqoritmi üzrə MAE 30 258 AZN, RMSE 36 150 AZN, R^2 isə −0,1397 olmuşdur. Mənfi determinasiya əmsalı modelin test seçməsində proqnozlaşdırma qabiliyyətinin zəif olduğunu və faktiki qiymətlərin orta göstəricisinə əsaslanan sadə yanaşmadan daha yaxşı nəticə vermədiyini göstərir. Gradient Boosting modelində MAE 28 518 AZN, RMSE 33 258 AZN, R^2 isə 0,0354 təşkil etmişdir. Bu nəticələr Gradient Boosting modelinin Random Forest ilə müqayisədə müəyyən üstünlüyə malik olduğunu göstərsə də, onun proqnozlaşdırma keyfiyyəti hedonik reqressiya modelindən əhəmiyyətli dərəcədə aşağıdır. Beləliklə, eksperiment çərçivəsində maşın öyrənməsi alqoritmlərinin tətbiqi gözlənilən üstünlüyü təmin etməmiş, ən yaxşı nəticə ənənəvi statistik model vasitəsilə əldə olunmuşdur[12].

Dünya təcrübəsində daşınmaz əmlakın kütləvi qiymətləndirilməsi zamanı hedonik reqressiya modelləri ilə yanaşı, qərar ağacları, ansambl öyrənmə metodları və digər maşın öyrənməsi

yanaşmalarından da istifadə edilir. Bu metodların tətbiqi xüsusilə geniş məlumat bazalarında, çoxsaylı qiymət amilləri arasında qeyri-xətti əlaqələrin mövcud olduğu hallarda əhəmiyyət kəsb edir. Beynəlxalq təcrübədə müxtəlif modellərin müqayisəsi zamanı onların üstünlüyü yalnız alqoritmin növü ilə deyil, məlumatların həcmi və keyfiyyəti, əmlak bazarının xüsusiyyətləri, giriş dəyişənlərinin düzgün seçilməsi və model parametrlərinin optimallaşdırılması ilə əlaqələndirilir. Buna görə də bir ölkənin və ya şəhərin daşınmaz əmlak bazarında uğurlu nəticə göstərən modelin digər bazarlarda da eyni dəqiqliyi nümayiş etdirəcəyi əvvəlcədən qəbul edilə bilməz[15].

Aparılmış tədqiqatın nəticələri də bu yanaşmanı təsdiqləyir. Belə ki, sintetik məlumat bazasında mənzil qiymətinin formalaşması sahə, yerləşmə, təmir vəziyyəti və digər göstəricilərlə müəyyən edilmiş qanunauyğunluqlar əsasında modelləşdirilmişdir. Hedonik reqressiya modeli bu asılılıqları test seçməsində daha uğurla əks etdirmişdir. Random Forest və Gradient Boosting modellərində isə yüksək təlim nəticələrinə baxmayaraq, test göstəricilərinin zəif olması modellərin yeni müşahidələr üzrə ümumiləşdirmə imkanlarının məhdudlaşdığını göstərir. Bu fərq maşın öyrənməsi modellərinin qiymətləndirilməsində yalnız təlim məlumatları üzrə yüksək uyğunlaşma göstəricilərinə əsaslanmağın kifayət etmədiyini, müstəqil test seçməsinin nəticələrinin də nəzərə alınmasının vacibliyini ortaya qoyur. Nəticə etibarilə, əldə edilmiş eksperimental göstəricilər əsasında hedonik reqressiya modeli tədqiqatda istifadə olunan sintetik məlumat bazası üçün daha məqsədəuyğun yanaşma kimi müəyyən edilmişdir. Bununla belə, alınmış nəticələri Bakı şəhərinin real daşınmaz əmlak bazarına birbaşa aid etmək düzgün olmazdı. Modelin praktik tətbiq imkanlarının daha dəqiq müəyyənləşdirilməsi üçün real satış qiymətləri, əmlak elanları və digər etibarlı bazar məlumatları əsasında əlavə sınaqların aparılması, həmçinin maşın öyrənməsi modellərinin parametrlərinin optimallaşdırılması tələb olunur. Bu baxımdan aparılmış eksperiment daşınmaz əmlakın kütləvi qiymətləndirilməsində müxtəlif metodların müqayisəsi üçün ilkin hesablama və metodoloji əsas yaradır [10, 11].

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Обнаружение новых фишинговых сайтов по признакам адреса и содержимого страницы методами машинного обучения

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Аннотация. Число фишинговых атак на пользователей информационных систем быстро растёт, а чёрные списки, которые должны от них защищать, обновляются с задержкой и ничего не знают о только что созданных сайтах. Цель работы - построить модель машинного обучения, которая выявляет фишинговые сайты по признакам веб-адреса и содержимого страницы, и сравнить её с проверкой по чёрному списку. Случайный лес и градиентный бустинг обучены на открытом наборе Phishing Websites (репозиторий UCI): n = 11 055 записей, из них 4 898 фишинговых; выборка разделена на обучающую и тестовую в соотношении 80 к 20. На тестовой выборке из 2 211 записей случайный лес показал точность 97,7 % и полноту 96,7 %, градиентный бустинг - 95,0 % и 93,8 %, а признак чёрного списка из того же набора дал 56,7 % и 16,8 %. Пятикратная перекрёстная проверка дала у случайного леса 97,0 ± 0,3 %, а исключение признака чёрного списка из входов модели точность не изменило. Разрыв в 41 процентный пункт относится именно к этому признаку, а не к промышленным службам блокировки; проверка на свежих адресах остаётся задачей следующего этапа. Модель пригодна как второй рубеж защиты, который администратор информационной системы ставит после списков.

Ключевые слова: фишинговые сайты; обнаружение фишинга; машинное обучение; защита от фишинговых атак; модель классификации.

1. Введение

Чёрный список нашёл 165 фишинговых сайтов из 980. Остальные 815 дошли бы до пользователя без единого предупреждения. Так выглядит проверка по списку на нашей тестовой выборке, и сразу оговоримся: «список» здесь - один из признаков исследуемого набора, а не промышленная служба вроде Google Safe Browsing. Что это меняет, мы разберём в обсуждении. Сам же механизм провала от оговорки не зависит: список знает только то, что кто-то уже заметил и записал.

Между появлением фишингового сайта и записью о нём проходит время, и в этот промежуток сайт ничем не ограничен. Модель, которая судит по самому сайту - по адресу, сертификату, ссылкам на странице, - от такой задержки не зависит.

Подходы этого рода описаны. Евдошенко и Лежнина строят классификатор вредоносных адресов на TF-IDF-признаках и логистической регрессии; в их результатах есть 261 ложное срабатывание, и авторы приходят к выводу, что одной модели недостаточно, нужен комплексный подход [1]. Султанова сравнивает пять алгоритмов на том же открытом наборе, что взяли и мы, и получает около 97 % у случайного леса [2]. Та же задача на уровне доменных имён разбирается в зарубежной литературе [3]. Чего мы не нашли в доступных русскоязычных работах, так это прямого сопоставления модели с проверкой по списку на одних и тех же записях. Эту пустоту и закрывает наша работа.

Цель - разработать модель машинного обучения для обнаружения новых фишинговых сайтов и сравнить её точность с проверкой по чёрному списку. Для этого нужно сделать четыре вещи: обзор методов, отбор признаков адреса и содержимого страницы, обучение и проверка моделей на открытом наборе, сравнение со списком.

2. Материалы и методы

Данные - набор Phishing Websites из репозитория UCI [4]. В нём 11 055 записей: 4 898 фишинговых (класс -1) и 6 157 легитимных (класс 1). Каждая запись описана 30 признаками адреса и содержимого страницы. Важная деталь: самих адресов в наборе нет, только готовые значения признаков, поэтому модель никогда не видит строку адреса, а видит её описание.

Выборку разделили случайно, но с сохранением долей классов: 80 % на обучение (8 844 записи), 20 % на проверку (2 211 записей, из них 980 фишинговых и 1 231 легитимная). Деление выполнено один раз, с фиксированным зерном случайных чисел.

Обучали два алгоритма: случайный лес из 200 деревьев [5] и градиентный бустинг [6]. Остальные параметры оставили по умолчанию библиотеки scikit-learn [7]; расчёты шли в Python в среде Google Colab. Качество измеряли тремя числами: точность (доля верных ответов), полнота (доля найденных фишинговых сайтов) и прецизионность (доля настоящих фишинговых среди тех, что модель назвала фишинговыми).

Чёрный список мы представили признаком набора statistical_report: он показывает, числится ли сайт среди известных фишинговых доменов и адресов. Значение -1 считали вердиктом «фишинг» и оценивали признак как самостоятельный классификатор на тех же 2 211 записях. В основном эксперименте этот признак остался среди входов обеих моделей; что будет без него, проверили отдельно.

Чтобы оценить устойчивость, дополнительно выполнили пятикратную стратифицированную перекрёстную проверку на всех 11 055 записях (зерно случайных чисел 42) и повторили её после удаления из входов признака statistical_report. Приводим среднюю точность по пяти разбиениям и стандартное отклонение.

3. Результаты

Оба алгоритма с большим запасом обошли список (табл. 1).

Таблица 1. Качество на тестовой выборке (2 211 записей)

Метод	Точность	Полнота	Прецизионность	Ложные тревоги / пропуски
Случайный лес	97,7 %	96,7 %	98,0 %	19 / 32
Градиентный бустинг	95,0 %	93,8 %	94,9 %	49 / 61
Чёрный список (statistical_report)	56,7 %	16,8 %	53,6 %	143 / 815

Случайный лес ответил верно в 2 160 случаях из 2 211 и ошибся 51 раз: 19 легитимных сайтов назвал фишинговыми и 32 фишинговых пропустил. Бустинг ошибся 110 раз. Список правильно определил 1 253 записи, пропустил 815 фишинговых сайтов из 980 и ложно пометил 143 легитимных. Прирост точности леса над списком - 41,0 процентного пункта, бустинга - 38,4. Заявленные в цели 10 пунктов превзойдены с многократным запасом.

Распределение важности признаков в лесу получилось резко неравным (табл. 2). Два первых признака несут 57,4 % всей важности, три первых - почти две трети. Признак чёрного списка оказался за пределами первой десятки.

Таблица 2. Пять самых важных признаков случайного леса

Признак	Важность
sslfinal_state (состояние защищённого соединения)	0,325
url_of_anchor (доля якорных ссылок, не ведущих на собственный домен)	0,249
web_traffic (посещаемость сайта)	0,074
having_sub_domain (число поддоменов)	0,063
links_in_tags (ссылки внутри служебных тегов страницы)	0,042

Перекрёстная проверка подтвердила порядок величин (табл. 3). Средняя точность по пяти разбиениям: 97,0 % у леса и 94,9 % у бустинга, разброс не выше 0,4 пункта. Исключение признака чёрного списка точность не изменило: разница в сотые доли процента лежит внутри разброса.

Таблица 3. Точность при пятикратной перекрёстной проверке (среднее ± стандартное отклонение)

Модель	Все признаки	Без statistical_report
Случайный лес	97,01 ± 0,27 %	97,04 ± 0,30 %
Градиентный бустинг	94,85 ± 0,37 %	94,91 ± 0,42 %

4. Обсуждение

На одном делении лес обошёл бустинг на 2,7 пункта, при перекрёстной проверке - на 2,2, а разброс между разбиениями составляет 0,3-0,4 пункта. Значит, в пределах наших пяти разбиений преимущество леса устойчиво. Но параметры бустинга не подбирались, и вывод относится к его стандартным настройкам, а не к бустингу вообще. Твёрдо можно утверждать и другое: оба алгоритма с запасом превосходят список, а их точность по порядку величины совпадает с тем, что получила Султанова на том же наборе [2].

Самый неудобный вопрос к нашему сравнению - не подсматривает ли модель в тот самый признак, с которым её сравнивают. Проверка ответила: нет. Без statistical_report лес даёт 97,04 % против 97,01 % со всеми признаками, бустинг - 94,91 % против 94,85 %; разница лежит внутри разброса. Модель опирается на сам сайт, а не на запись в списке, и разрыв в 41 пункт не объясняется этим признаком.

Больше говорит структура ошибок. Лес пропускает фишинг (32) чаще, чем клевещет на честные сайты (19). Для защиты это неприятная асимметрия: пропуск обходится дороже ложной тревоги. Её можно сдвинуть порогом вероятности ценой роста ложных срабатываний; такой эксперимент мы не ставили, но направление ясно. Список ошибается иначе: молчит там, где нужно предупредить, и при этом всё равно даёт 143 ложные тревоги. Даже запись в нём, как видно по нашему набору, не равна приговору.

Признаки подсказывают, на чём модель держится. Имитатор без труда копирует вид страницы, но плохо подделывает то, что требует репутации: действующий сертификат, посещаемость, чистую ссылочную структуру. Это гипотеза. Мера важности показывает, что признак работает, и ничего не говорит о причине, так что проверять объяснение ещё предстоит.

Границы результата определяют четыре обстоятельства, и каждое его сужает. Первое: перекрёстная проверка даёт среднее и разброс, но не заменяет независимой выборки, ведь все записи принадлежат одному набору и одному периоду. Второе: набор

составлен в середине 2010-х, часть признаков, например посещаемость, зависит от внешних сервисов, а сам фишинг с тех пор изменился. Третье: «список» в нашем эксперименте - приближение, и 41 пункт разрыва измерен относительно него, а не относительно настоящей службы блокировки, которая могла бы показать результат лучше. Четвёртое: модель работала с готовыми признаками; чтобы применить её к живому адресу, нужен отдельный модуль, который эти признаки вычислит.

5. Выводы и следующий шаг

Для администратора вывод практический. Модель на признаках сайта стоит ставить вторым рубежом после списков, а не вместо них: списки дёшевы и быстры, модель ловит то, что они не успели записать. Насколько именно она их превосходит, пока сказать нельзя; 41 пункт - верхняя оценка, снятая с приближённого эталона. Чтобы заменить его настоящим, нужны свежая выборка адресов с собственным вычислением признаков и сопоставление с реальной службой блокировки. Это и есть следующий этап работы.

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Design and Frequency Response Study of the Output Stage of an Analog Optoelectronic Amplifier

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Abstract

The paper presents the theoretical foundations of a galvanically isolated analog amplifier built on the HCNR200 high-linearity analog optocoupler and the OPA354 operational amplifier. The transfer coefficient is derived for the input feedback loop and the output transimpedance stage, and the frequency response of the transimpedance stage is analyzed using a second-order model. Calculations performed in the MATLAB environment with the parameters taken from the manufacturers' datasheets show that increasing the feedback resistor from 10 kΩ to 1 MΩ raises the transimpedance by 40 dB, while the −3 dB bandwidth decreases from approximately 5.9 MHz to 0.77 MHz. A procedure for selecting the compensation capacitor is given.

Keywords: optocoupler, analog galvanic isolation, transimpedance amplifier, bandwidth.

Introduction

Galvanic isolation of analog signals is widely used in industrial automation, medical devices, and the feedback circuits of power converters. Linear analog optocouplers make it possible to solve this problem; however, the speed of an amplifier built on them depends on the optocoupler itself, on the frequency properties of the operational amplifiers, and on the photodiode capacitance.

The aim of this paper is to derive the transfer coefficient of an isolation amplifier based on the HCNR200 optocoupler and the OPA354 operational amplifier, to analyze the frequency response of the output transimpedance stage, and to evaluate the influence of the feedback resistor and the compensation capacitor on the bandwidth using the parameters given in the manufacturers' datasheets. [1,3]

1. Problems of Transmitting Analog Signals with Galvanic Isolation (Problem Statement)

In industrial automation, medical devices, and power electronics systems, the measured signal must be galvanically separated from the control part. Digital optocouplers transmit only a two-level signal. For the transmission of an analog signal, the main indicators are the linearity of the optocoupler's transfer characteristic, its temperature and time stability, and its speed. In optocouplers, the relationship between the current of the light-emitting diode (LED) and the current of the photodetector is nonlinear and varies with temperature and time. In addition, the level of the output signal is very small. For these reasons, their direct use for transmitting analog signals is limited.

To solve this problem, optocouplers consisting of one LED and two identical photodiodes (for example, the HCNR200/201) are used. One of the photodiodes is connected to the feedback circuit and the other to the output circuit [1].

2. Transfer and Matching Coefficients of the Optocoupler

Let us denote the LED current by I_F and the photocurrents of the first and second photodiodes by I_{P1} and I_{P2}, respectively. Then the transfer coefficients are defined by the following expression:

$$K_1 = \frac{I_{P1}}{I_F}, \quad K_2 = \frac{I_{P2}}{I_F}, \quad K_3 = \frac{K_2}{K_1} = \frac{I_{P2}}{I_{P1}} \tag{1}$$

Here K_1 and K_2 are the current transfer coefficients of the optocoupler. Individually, they are nonlinear and temperature-dependent. However, because the photodiodes are exposed to the radiation of the same LED, their current variations are approximately the same, and therefore the ratio of the currents, the matching coefficient K_3, remains practically constant. This property forms the basis of the accuracy of an analog isolation amplifier. The nominal value of K_3 is 1.00; the permissible deviation is ±15% for the HCNR200 and ±5% for the HCNR201; the typical value for K_1 and K_2 is 0.5% [1].

3. Operation of the Input Stage

In the input stage, the operational amplifier U1 drives the LED, and the current of the photodiode PD1 is returned to the noninverting (+) input of U1, while the inverting (–) input is grounded (Fig. 1). The input voltage V_{in} is applied to the same node through the resistor R_1.

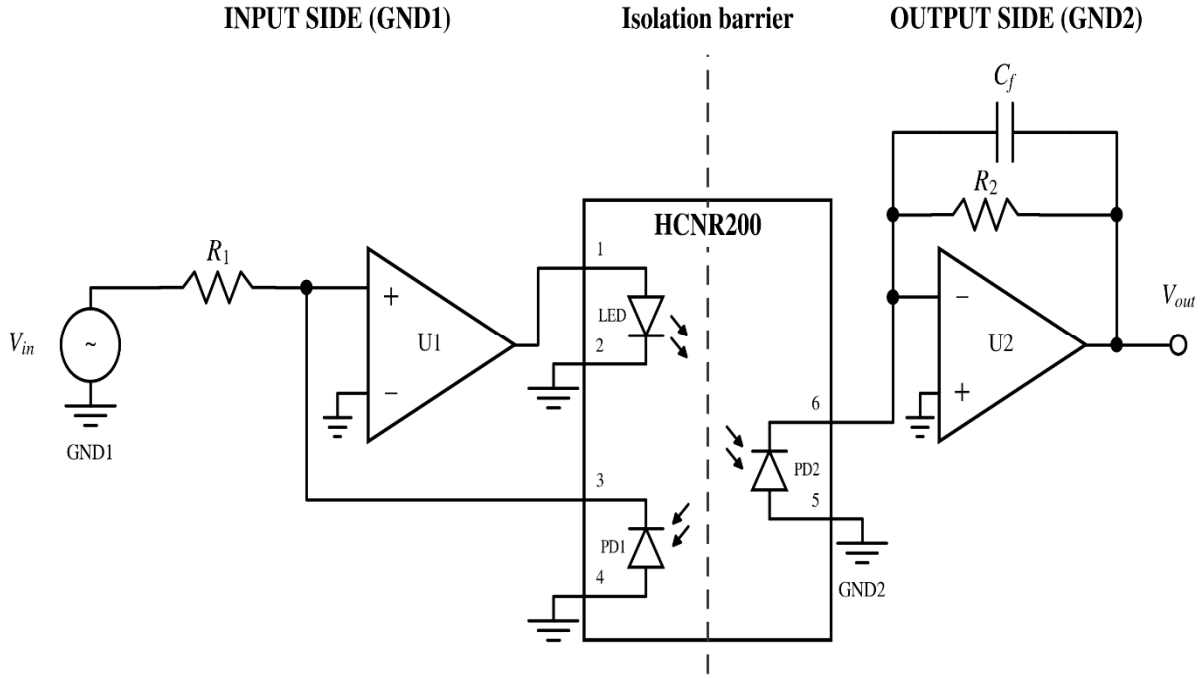


Fig. 1. Electrical schematic diagram of an analog isolation amplifier based on the HCNR200

U1, U2 – operational amplifiers (OPA354); R_1 – input resistor; R_2 – feedback resistor of the transimpedance stage; C_f – compensation capacitor; LED – light-emitting diode; PD1, PD2 – feedback and output photodiodes; GND1, GND2 – ground connections of the input and output sides.

Owing to the high gain of the operational amplifier, the potential at the noninverting input node is kept close to zero (the potential of the grounded inverting input), and since the algebraic sum of the currents entering the node is zero, the following expression can be written for the PD1 current:

$$\frac{V_{in}}{R_1} = I_{P1} \tag{2}$$

Thus, U1 adjusts the LED current so that the PD1 current is always equal to V_{in}/R_1. The nonlinearity and temperature drift of the LED are compensated through the feedback, because the feedback tracks the change in K_1 and changes the LED current accordingly.

4. Output Stage and Overall Transfer Coefficient

In the output stage, the current of the photodiode PD2 is converted into the output voltage by the transimpedance amplifier U2 (Fig. 1). R_2 is the feedback resistor:

$$V_{out} = I_{P2} \cdot R_2 \tag{3}$$

Taking into account that $I_{P2} = K_3 \cdot I_{P1}$ and equality (2), we obtain:

$$V_{out} = K_3 \cdot \frac{R_2}{R_1} \cdot V_{in} \tag{4}$$

This expression shows that the overall transfer coefficient of the analog isolation amplifier is determined only by the matching coefficient K_3 and the ratio of the resistors. The nonlinearity of the transfer coefficients K_1 and K_2 of the optocoupler does not affect the result. When signal inversion is required, the corresponding circuit variant is chosen.

5. Frequency Response of the Transimpedance Stage

The bandwidth of the device is limited by two factors: the speed of the feedback loop in the input stage (the response time of the LED, the capacitance of the photodiode PD1, and the frequency properties of the operational amplifier (op-amp) U1) and the bandwidth of the output transimpedance stage. This section analyzes the output stage.

Let us describe the operational amplifier by a single-pole model:

$$A(s) = \frac{\omega_t}{s}, \quad \omega_t = 2\pi \cdot GBW \tag{5}$$

With the input capacitance C_{in} (the sum of the capacitances of the photodiode PD2 and the input capacitance of the op-amp) at the input, and R_f and C_f connected in parallel in the feedback circuit (here $R_f = R_2$), the transfer function is obtained as follows:

$$Z(s) = \frac{V_{out}}{I_{in}} = -\frac{R_f}{1+s\left(R_f C_f + \frac{1}{\omega_t}\right)+s^2\frac{R_f\left(C_{in}+C_f\right)}{\omega_t}} \tag{6}$$

This is a second-order system. Its natural frequency ω_0 and quality factor Q are:

$$\omega_0 = \sqrt{\frac{\omega_t}{R_f(C_{in}+C_f)}}, \quad Q = \frac{1}{\omega_0\left(R_f C_f + \frac{1}{\omega_t}\right)} \tag{7}$$

When C_f is small, the quality factor Q is large, peaking occurs in the amplitude–frequency response (AFR), and the system approaches the stability limit. As C_f is increased, Q decreases. For a maximally flat AFR (Butterworth response, $Q \approx 0.707$), C_f is chosen approximately as:

$$C_f \approx \sqrt{\frac{2C_{in}}{\omega_t R_f}} \tag{8}$$

In this case, the −3 dB bandwidth is:

$$f_{-3dB} \approx \sqrt{\frac{GBW}{2\pi R_f C_{in}}} \tag{9}$$

This expression shows that to increase the bandwidth, an op-amp with a higher GBW (Gain-Bandwidth Product), a smaller R_f, and a smaller C_{in} should be chosen. However, decreasing R_f also changes the transfer coefficient (R_2/R_1) and the signal-to-noise ratio; therefore, a compromise is required in the design.

6. Design Findings and Recommendations

1) The transfer accuracy is determined by the stability of the matching coefficient K_3 and by the accuracy of the resistors.
2) The speed depends on GBW, R_f, and C_{in} in the output stage, and on the speed of the feedback loop in the input stage. The overall bandwidth is limited by the smaller of the two.
3) The capacitor C_f determines the shape and stability of the AFR; choosing its optimal value is one of the main stages of the design.

4) The theoretical estimates are verified by calculation in the MATLAB environment in the next section.

7. Calculation Parameters and Methodology

The calculations were performed in the MATLAB environment (Control System Toolbox, MATLAB R2026b) on the basis of transfer functions. The operational amplifier is described by a single-pole model defined by the GBW (5), and the LED of the optocoupler by a first-order element with a −3 dB frequency f_{LED}:

$$H_{opt}(s) = \frac{1}{1+\frac{s}{2\pi f_{LED}}} \quad (10)$$

The overall transfer function of the output stage is taken as the product of the transfer function of the transimpedance stage (6) and that of the optocoupler:

$$Z_{total}(s) = Z(s) \cdot H_{opt}(s) \quad (11)$$

The parameters used in the calculations are given in Table 1. The capacitance C_{in} is taken as the sum of the HCNR200 photodiode capacitance and the differential and common-mode input capacitances of the OPA354; the parasitic capacitance of the PCB is not taken into account. Because the noninverting input of the op-amp U2 is grounded, the photodiode PD2 operates in a mode close to zero bias; therefore, the photodiode capacitance value specified for V_{PD} = 0 V is used. The capacitance C_f is calculated using formula (8). The values 10 kΩ, 47 kΩ, 100 kΩ, and 1 MΩ are selected for R_f.

Table 1. Parameters used in the calculations

Parameter	Value	Source
OPA354: GBW	100 MHz	[2]
OPA354: input capacitance (differential + common-mode)	2 pF + 2 pF = 4 pF	[2]
HCNR200: photodiode capacitance C_{PD} (V_{PD} = 0 V)	22 pF	[1]
$C_{in} = C_{PD}$ + 4 pF	26 pF	calculated
HCNR200: LED bandwidth f_{LED} (I_F = 10 mA)	9 MHz	[1]
HCNR200: K_3 (nominal; permissible range)	1.00 (0.85 – 1.15)	[1]

8. Results and Discussion

The calculation results are given in Fig. 2 and Table 2. In the table, f_{TIA} is the bandwidth of the transimpedance stage alone, and f_{total} is the bandwidth at the −3 dB level with the LED bandwidth also taken into account.

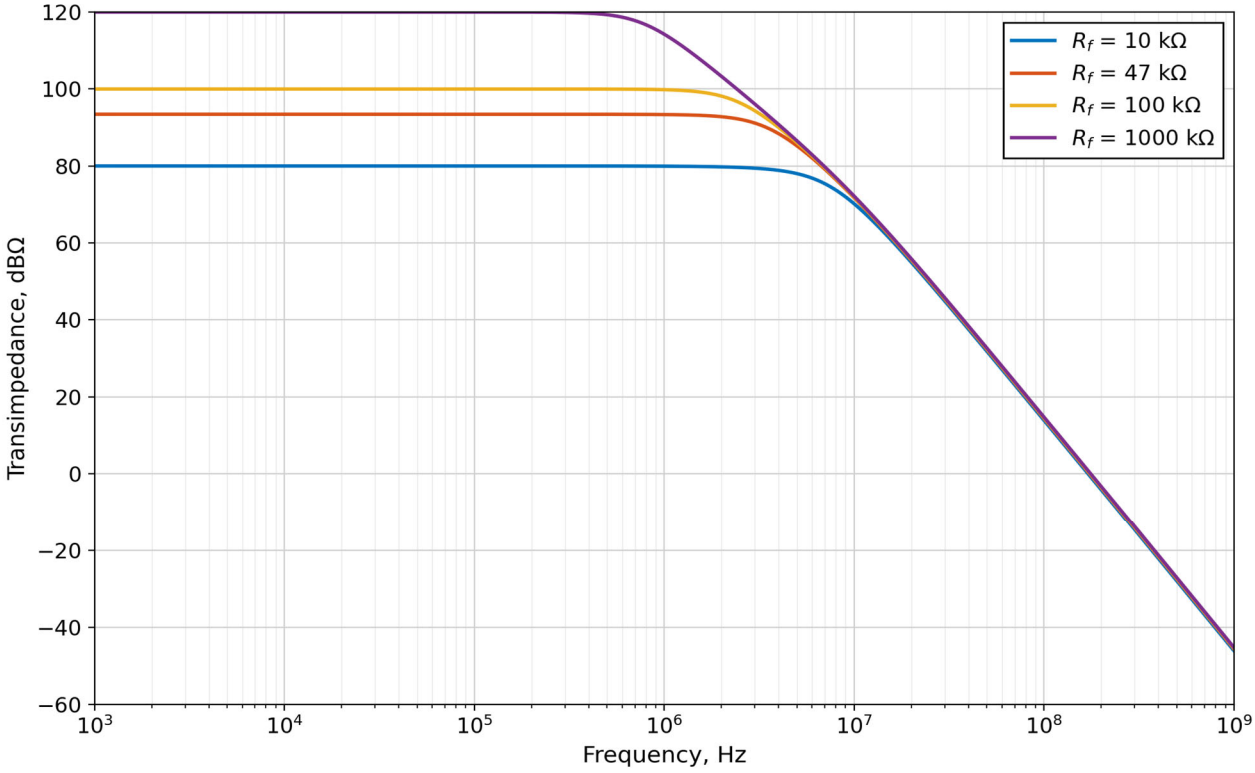


Fig. 2. Amplitude–frequency response of the output transimpedance stage for different values of R_f (based on the OPA354, with the HCNR200 LED bandwidth taken into account)

Table 2. Calculation results for different values of R_{f}

R_f, kΩ	Z_0, dBΩ	C_f, pF	f_{TIA}, kHz	f_{total}, kHz
10	80.0	2.88	7405	5883
47	93.4	1.33	3515	3286
100	100.0	0.91	2429	2347
1000	120.0	0.29	777	774

The following can be seen from the results.

First, there is a trade-off between gain and speed. Increasing R_f from 10 kΩ to 1 MΩ (by a factor of 100) increases the transimpedance by 40 dB and reduces the bandwidth by approximately a factor of 7.6 (from 5883 kHz to 774 kHz). In accordance with formula (9), the dependence of the bandwidth on R_f is approximately inversely proportional to the square root of R_f.

Second, the C_f selected by formula (8) ensures the absence of peaking in the AFR in all cases (Fig. 2). The bandwidth calculated by formula (9) differs from the MATLAB results by no more than 6%; the difference increases as R_f decreases, because the formula assumes C_f to be small compared with C_{in}.[5]

Third, the bandwidth of the optocoupler LED (9 MHz) plays a significant role only at small values of R_f: for R_f = 10 kΩ, the overall bandwidth is approximately 21% smaller than the bandwidth of the transimpedance stage; for R_f = 100 kΩ the difference falls to 3.4%, and for R_f = 1 MΩ to 0.4%. Thus, at large values of R_f, the speed is limited not by the optocoupler but by the output stage.

Fourth, for large R_f the required C_f is very small (0.29 pF for R_f = 1 MΩ). The manufacturer's datasheet for the OPA354 recommends subtracting the parasitic capacitance of the resistor,

approximately 0.2 pF, from the calculated C_f [2]; in this case, the actual C_f is approximately 0.1 pF and is difficult to realize accurately in practice.

The results obtained should be assessed with the limitations of the model in mind. The model does not take into account the input feedback loop (U1, the capacitance of PD1, R_1); therefore, the calculated bandwidth should be regarded as an upper limit for a real system. The manufacturer's datasheet specifies a bandwidth of approximately 1.5 MHz for the high-speed application circuit [1]; this figure refers to a different circuit (amplifiers built with discrete transistors) and should not be compared directly with our calculation. In addition, the op-amp is assumed to be single-pole, and noise and nonlinearity are not taken into account.[4]

9. Conclusion

1) The transfer coefficient of an isolation amplifier based on the HCNR200 optocoupler is determined only by K_3 and the ratio R_2/R_1 and does not depend on the nonlinearity of the LED.
2) With the manufacturers' parameters of the OPA354 and HCNR200 (GBW = 100 MHz, C_{in} = 26 pF, f_{LED} = 9 MHz), increasing R_f from 10 kΩ to 1 MΩ raises the transimpedance from 80 dBΩ to 120 dBΩ and reduces the −3 dB bandwidth from 5.9 MHz to 0.77 MHz.
3) The C_f selected by formula (8) ensures stable operation of the AFR without peaking.
4) The bandwidth of the LED noticeably limits the overall bandwidth only at small values of R_f (below approximately 100 kΩ).
5) In future work, the input feedback loop should also be taken into account, and the results should be verified by SPICE simulation or experiment.

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A METHODOLOGY FOR BUILDING AN ATTACK DETECTION DATASET ON A 5G TESTBED BASED ON OPEN5GS AND UERANSIM

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Abstract. The quality of machine learning based intrusion detection in 5G networks depends directly on the data used to train it. The widely used CIC-IDS2017, UNSW-NB15 and BoT-IoT datasets were collected in conventional IP networks and therefore contain no GTP-U tunnelling, no NGAP signalling and no network slices. This paper describes a 5G standalone testbed built in VirtualBox from the Open5GS core and the UERANSIM gNB/UE simulator. It presents the benign and attack traffic scenarios, packet capture on the N3 and N6 interfaces, GTP-U decapsulation, flow labelling from an experiment manifest, and a data split that prevents leakage between training and test sets. The methodology is used in a doctoral study to build a dataset for training and validating a hybrid, explainable IDS model.

Keywords: 5G, intrusion detection system, dataset, Open5GS, UERANSIM, GTP-U, network slicing, machine learning.

Introduction

Fifth-generation mobile networks deliver eMBB, URLLC and mMTC services over a shared infrastructure by means of network slicing. The 5G core follows a service-based architecture: AMF, SMF, UPF, NRF, AUSF and other network functions communicate over the HTTP/2-based SBI [1]. Virtualisation, open interfaces and the large number of IoT devices widen the attack surface. The ENISA report shows that a considerable share of 5G threats concerns core network functions, the control plane and the virtualisation layer [2].

Most studies of machine learning based intrusion detection systems (IDS) use the CIC-IDS2017 [3], UNSW-NB15 [4] and BoT-IoT [5] datasets. These were collected in enterprise or IoT networks and contain no GTP-U encapsulation, no NGAP or PFCP signalling and no slice identifiers. The 5G-NIDD dataset [6], captured on a real 5G network, partly fills this gap, but its scenarios and topology are fixed, so a researcher cannot add a new attack type or slice configuration. Labelling errors are also known to occur in public IDS datasets [7], which makes it important to be able to verify how labels were assigned.

For these reasons, running controlled experiments on one's own testbed and assigning labels from the experiment log is a justified approach. The aim of this paper is to describe how a 5G SA testbed is built with the open-source Open5GS [8] and UERANSIM [9] tools and how a labelled attack detection dataset is produced on it. The work is part of a doctoral dissertation on the research and development of a method for ensuring information security in 5G/6G networks using an intelligent attack detection and prevention system.

1. Comparison of existing datasets

Table 1 lists the properties of datasets commonly used in IDS research with respect to the 5G environment.

Table 1 – Comparison of datasets

Dataset	Year	Capture environment	5G traffic	Limitations
CIC-IDS2017 [3]	2017	Enterprise LAN	No	No GTP-U or slices; labelling errors reported [7]
UNSW-NB15 [4]	2015	IXIA PerfectStorm generator	No	Synthetic traffic, no mobile core
BoT-IoT [5]	2019	Virtual IoT network	No	Severe class imbalance, no 5G signalling
5G-NIDD [6]	2022	Real 5G testbed (Oulu)	Yes	Fixed scenarios, no slice-level labels

Conventional datasets lack the protocol layers specific to 5G, and 5G-NIDD cannot be extended. The proposed testbed is not meant to replace these datasets but to complement them and to allow models to be tested across different environments.

2. Testbed architecture

The testbed runs on Ubuntu virtual machines under the VirtualBox hypervisor. The first machine hosts the Open5GS core (AMF, SMF, UPF, NRF, AUSF, UDM, UDR, PCF, NSSF) and the MongoDB subscriber database. The second machine runs UERANSIM gNB and UE instances; after registration each UE obtains a uesimtun virtual interface and reaches the data network (DN) through a PDU session. The third machine plays the role of the data network on the N6 side and hosts a web server, an iperf3 server and services used as attack targets. Clocks are synchronised with chrony, which is required to match timestamps during labelling.

To separate slices, several S-NSSAI values are configured in the core and the UEs (SST=1 for eMBB, SST=2 for URLLC, SST=3 for mMTC), each with its own IP pool. The slice of any flow can therefore be determined from the UE address. The main testbed interfaces are given in Table 2.

Table 2 – Testbed interfaces and capture points

Interface	Nodes	Protocol	Role in the dataset
N2	gNB – AMF	NGAP / SCTP (38412)	Control plane: registration, session signalling
N3	gNB – UPF	GTP-U / UDP (2152)	Tunnelled user traffic; main capture point
N4	SMF – UPF	PFCP / UDP (8805)	Session rules; monitoring inside the core
N6	UPF – DN	IP	Traffic after the tunnel; additional capture point
SBI	Core functions	HTTP/2	Interaction between core network functions

3. Traffic scenarios

Benign traffic is generated by several UEs: TCP and UDP iperf3 flows (eMBB), short latency-bounded request-response exchanges (URLLC), small periodic messages resembling IoT devices (mMTC), and HTTP downloads with curl and ICMP requests. Attack traffic is sent from a separate compromised UE, so benign and malicious traffic are not mixed on one UE. The attack types were chosen to be comparable with the categories in 5G-NIDD (Table 3).

Table 3 – Attack scenarios on the testbed

Attack class	Tool	Target	Plane
ICMP / UDP flood	hping3	DN servers	User plane
TCP SYN flood	hping3	DN web server	User plane
Slow HTTP attack (Slowloris)	slowloris	DN web server	User plane
TCP SYN / UDP scan	nmap	DN network, other UEs	User plane
Registration storm	UERANSIM (many UEs)	AMF	Control plane

Each experiment is numbered EXP-xxx and covers one attack type with its parameters (rate, duration, ports) and slice. Benign traffic runs continuously before and after the attack phase, so the model can observe both the start and the end of an attack.

4. Data collection and labelling methodology

The dataset is produced in the following stages.

1) Experiment manifest. For each experiment a JSON manifest is written containing the experiment number, attack start and end times, the attacking UE's IP address, the target address, the tool and its parameters, and the slice. The manifest is filled in automatically by the launch script, so timestamps are never entered by hand.

2) Packet capture. tcpdump runs simultaneously on the N3 and N6 interfaces and writes pcap files. NGAP messages on the N2 interface are captured separately for control-plane attacks.

3) GTP-U decapsulation. The outer IP/UDP/GTP-U headers of packets captured on N3 are removed, the inner UE packets are restored, and the TEID value is kept as an additional field. Without this step flow analysis tools see all traffic as a single UDP flow between the gNB and the UPF.

4) Feature extraction. Bidirectional flows are built from the inner packets and their statistical features are computed (packet and byte counts, duration, inter-arrival times, TCP flags). In addition, aggregate per-UE features are computed over a fixed time window, for example the number of distinct destination ports and the share of SYN packets. Such features help to detect scanning and flooding that are not visible in individual flows.

5) Labelling. A flow is assigned to an attack class if its source is the attacking UE address from the manifest and its time lies fully within the attack interval. Flows crossing the boundary of the attack interval receive a separate label and are excluded from the main experiments. Traffic from the attacking UE outside the attack interval is labelled benign. Each flow also receives a slice label (eMBB, URLLC, mMTC).

6) Quality checks. After labelling, each experiment is checked for class distribution, unlabelled flows, duplicate records and agreement between manifest and pcap timestamps. An experiment that fails the checks is excluded and repeated.

7) Train/test split. A random split of flows places highly similar flows from the same experiment into both training and test sets, which inflates model performance [10]. The split is therefore made at the experiment level: all flows of one EXP belong to one part only. As an

additional protocol, a leave-one-attack-out setting is considered, in which one attack type appears only in the test set, to evaluate the detection of previously unseen attacks.

5. Discussion

The main advantage of the approach is that every label is tied directly to the experiment log, so its origin can be verified. Because the testbed configuration and scripts are preserved, experiments are easy to repeat and new attack types are easy to add. The slice label makes it possible to evaluate model quality separately for eMBB, URLLC and mMTC.

The methodology also has limitations. UERANSIM does not model the radio channel, so physical-layer attacks such as jamming are not covered. Throughput in a virtual environment is lower than in a real network, and synthetic benign traffic does not fully reproduce real user behaviour. For this reason the testbed data are planned to be used together with real-network data such as 5G-NIDD, with models trained in one environment and tested in the other.

Conclusion

The paper described how a 5G SA testbed is built with Open5GS and UERANSIM and how an attack detection dataset is produced on it. The methodology combines an experiment manifest, traffic capture on the N3 and N6 interfaces, GTP-U decapsulation, flow and window features, manifest-based labelling and an experiment-level split. The resulting dataset will be used in the doctoral study to train a hybrid, explainable attack detection model, to evaluate it per slice and to test its robustness to unseen attacks. The next stage is the development of a software prototype in an SDN/NFV environment.

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Medical Sciences

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ЖАСАНДЫ ИНТЕЛЛЕКТ ПЕН НЕЙРОНДЫҚ ЖЕЛІЛЕРДІҢ МЕДИЦИНАЛЫҚ ТЕХНОЛОГИЯЛАРДЫҢ ДАМУЫНА ӘСЕРІ

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Аңдатпа. Мақалада медицинада жасанды интеллект пен нейрондық желі технологияларын қолданудың негізгі бағыттары қарастырылады. Ауруларды диагностикалау, медициналық кескіндерді талдау, клиникалық шешімдерді қолдау және емдеуді жекелендіру мүмкіндіктері сипатталады. Сонымен қатар медициналық үдерістерді автоматтандырудың артықшылықтары, алгоритмдердің дәлдігіне, деректер сапасына, жеке ақпаратты қорғауға және этикалық мәселелерге байланысты шектеулері талданады. Жасанды интеллект жүйелерін клиникалық тексерудің және медициналық шешім қабылдауда дәрігердің жетекші рөлін сақтаудың маңыздылығы көрсетіледі.

Түйін сөздер: жасанды интеллект, нейрондық желілер, медицина, диагностика, машиналық оқыту, цифрлық денсаулық сақтау.

Өзектілігі. Ақпараттық технологиялардың қазіргі заманғы дамуы қоғамдық өмірдің әртүрлі салаларына, соның ішінде денсаулық сақтау жүйесіне де елеулі ықпал етуде. Соңғы жылдары медициналық ұйымдар пациенттердің денсаулық жағдайы туралы ақпаратты сақтау, өңдеу және талдау үшін цифрлық технологияларды жиі қолдана бастады. Медициналық мекемелерде күн сайын зертханалық талдау нәтижелерін, электрондық медициналық карталарды, рентгенологиялық кескіндерді, ультрадыбыстық зерттеу, компьютерлік және магниттік-резонанстық томография деректерін, сондай-ақ пациенттердің жағдайындағы өзгерістер туралы мәліметтерді қамтитын үлкен көлемдегі ақпарат қалыптасады.

Мұндай ақпарат көлемін өңдеу айтарлықтай уақытты, медицина қызметкерлерінің жоғары біліктілігін және деректерді талдаудың заманауи әдістерін қолдануды талап етеді. Осыған байланысты жасанды интеллект пен нейрондық желі технологиялары медициналық көмекті жетілдіруде ерекше маңызға ие болып отыр. Оларды пайдалану диагностиканың

тиімділігін арттыруға, медицина персоналының жұмысын оңтайландыруға және емдеу үдерісін ұйымдастыруды жетілдіруге қосымша мүмкіндіктер ашады.

Жасанды интеллект (ЖИ) – компьютерлік жүйелерге ақпаратты талдау, бейнелерді тану, деректерді жіктеу, заңдылықтарды анықтау және нәтижелерді болжау сияқты міндеттерді орындауға мүмкіндік беретін әдістер мен технологиялар жиынтығы. Жасанды интеллектінің маңызды бағыттарының бірі – машиналық оқыту. Бұл тәсілде компьютерлік жүйе көптеген мысалдар негізінде оқытылып, белгілі бір міндеттерді орындау сапасын біртіндеп жақсартады.

Нейрондық желілер жасанды интеллектінің негізгі құралдарының бірі болып табылады. Олар биологиялық нейрондық жүйелердің ұйымдасу ерекшеліктеріне негізделген есептеу модельдері ретінде қарастырылады. Мысалдар арқылы оқыту қабілетінің арқасында нейрондық желілер үлкен ақпарат массивтеріндегі күрделі заңдылықтарды анықтай алады. Көпқабатты нейрондық желілерді пайдалануға негізделген терең оқыту медициналық кескіндерді, мәтіндік деректерді және физиологиялық сигналдарды өңдеуде кеңінен қолданылады [1, 2].

Бұл тақырыптың өзектілігі медициналық диагностиканың дәлдігі мен жеделдігін арттыру қажеттілігімен де байланысты. Патологиялық өзгерістерді уақтылы анықтау пациентті әрі қарай тексеру және емдеу тактикасын белгілеу үшін маңызды. Интеллектуалды жүйелер ақпаратты қысқа уақыт ішінде талдап, маманның қосымша бағалауын қажет ететін белгілерге назар аударта алады.

Дүниежүзілік денсаулық сақтау ұйымы жасанды интеллектінің диагностикада, емдеуде, медициналық зерттеулерде және денсаулық сақтауды ұйымдастыруда елеулі әлеуеті бар екенін атап көрсетеді. Сонымен қатар мұндай технологияларды қолдану қауіпсіздік, ашықтық, әділдік, пациенттердің құқықтарын қорғау және медицина қызметкерлерінің жауапкершілігі қағидаттарын сақтаумен қатар жүруі тиіс [3].

Осылайша, медицинадағы жасанды интеллект мүмкіндіктерін зерттеу өзекті бағыт болып табылады, өйткені цифрлық технологияларды енгізу заманауи денсаулық сақтау жүйесінің дамуына және медициналық көмектің сапасын арттыруға ықпал етуі мүмкін.

Мақаланың мақсаты – медицинада жасанды интеллект пен нейрондық желі технологияларын пайдаланудың негізгі бағыттарын қарастыру, олардың артықшылықтары мен шектеулерін анықтау, сондай-ақ интеллектуалды жүйелерді практикалық денсаулық сақтау саласына, оның ішінде Қазақстан Республикасында енгізу перспективаларын сипаттау.

Зерттеу нәтижелері.Бұл жұмыс денсаулық сақтау саласында жасанды интеллектіні қолдануға арналған ғылыми жарияланымдар мен халықаралық ұйымдардың ұсынымдарына аналитикалық шолу болып табылады. Талдау барысында машиналық және терең оқытудың негізгі мүмкіндіктері, медициналық ақпаратты өңдеуде нейрондық желілерді пайдаланудың ерекшеліктері, сондай-ақ интеллектуалды технологияларды енгізудің артықшылықтары мен ықтимал тәуекелдері қарастырылды.

Ғылыми дереккөздерді талдау жасанды интеллектіні қолданудың бірнеше негізгі бағытын анықтауға мүмкіндік берді: ауруларды диагностикалау, медициналық кескіндерді өңдеу, клиникалық шешімдерді қолдау, емдеуді жекелендіру, дәрілік препараттарды әзірлеу және медициналық құжаттаманы автоматтандыру.

ЖИ-ді ауруларды диагностикалауда қолдану

Жасанды интеллектіні қолданудың ең перспективалы бағыттарының бірі – медициналық диагностика. Заманауи нейрондық желі алгоритмдері медициналық кескіндердің әртүрлі түрлерін талдап, белгілі бір патологиялық өзгерістерді анықтай алады және мамандарға зерттеу нәтижелерін түсіндіруге көмектеседі.

Сәулелік диагностикада жасанды интеллект алгоритмдері рентгенограммаларды,

компьютерлік және магниттік-резонанстық томограммаларды өңдеу үшін қолданылады. Олар күмәнді аймақтарды анықтауға, патологиялық түзілістердің өлшемдерін белгілеуге, тіндер құрылымындағы өзгерістерді табуға және автоматты өлшеулер жүргізуге көмектесе алады. Мұндай мүмкіндіктер медициналық кескіндердің көп мөлшерін зерттеу кезінде ерекше маңызды, өйткені алдын ала талдауды жеделдетіп, алынған нәтижелерді жүйелеуге мүмкіндік береді.

Мысалы, кеуде қуысы ағзаларының рентгенологиялық кескіндерін талдау кезінде интеллектуалды жүйелер өкпе тініндегі патологиялық өзгерістердің белгілерін анықтауға көмектесе алады. Компьютерлік томографияда алгоритмдер маманның мұқият қарауын қажет ететін аймақтарды белгілеу үшін пайдаланылуы мүмкін. Алайда нәтижелерді түпкілікті түсіндіру клиникалық көрініс пен басқа диагностикалық деректерді ескере отырып, дәрігер тарапынан жүргізілуі тиіс.

Нейрондық желі технологиялары ультрадыбыстық диагностикада да маңызды орын алады. Ультрадыбыстық зерттеу қолжетімділігі, инвазивті еместігі және ішкі ағзалардың жағдайын нақты уақыт режимінде бақылау мүмкіндігіне байланысты медицинаның әртүрлі салаларында кеңінен қолданылады. Бұл ретте зерттеу сапасы көбінесе маманның тәжірибесіне, датчиктің орналасуына және жабдық параметрлерін дұрыс таңдауға байланысты.

Ультрадыбыстық диагностикада жасанды интеллект анатомиялық құрылымдарды тану, стандартты кескіндерді анықтау және өлшеулерді автоматтандыру үшін қолданылуы мүмкін. Мысалы, эхокардиография кезінде интеллектуалды алгоритмдер жүрек қуыстарының өлшемдерін, миокард қабырғаларының қалыңдығын және жүрек қызметінің жекелеген көрсеткіштерін бағалауға көмектесе алады. Бұл алынған кескіндерді өңдеуді жеңілдетіп, өлшеулерді стандарттауға ықпал етеді.

Допплерографияда нейрондық желі технологиялары спектрлік қисықтарды талдау, қан ағымының сипаттамаларын бағалау және жекелеген өлшеулерді автоматтандыру үшін қолданылуы мүмкін. Мұндай құралдар маманның жұмысын жеңілдеткенімен, нәтижелерді кәсіби бағалау қажеттілігін жоймайды, өйткені ультрадыбыстық зерттеу зерттелетін аймақты дұрыс таңдауды және диагностикалық жабдықты тиісті деңгейде баптауды талап етеді.

Медицинаның басқа салаларында жасанды интеллект электрокардиограммаларды талдау, көз түбі кескіндерінен диабеттік ретинопатия белгілерін анықтау және зертханалық деректерді өңдеу үшін қолданылады. Нейрондық желілер медициналық ақпараттағы белгілі бір заңдылықтарды анықтай алады, бұл патологиялық өзгерістерді ерте кезеңде табуға көмектесуі мүмкін. Дегенмен алгоритм жұмысының нәтижелері нақты клиникалық практикаға сәйкес жағдайларда тексерілуі тиіс [1, 2].

Клиникалық шешімдерді қолдау үшін ЖИ-ді пайдалану

Жасанды интеллектіні қолданудың тағы бір маңызды бағыты – клиникалық шешімдерді қолдау. Күнделікті тәжірибеде дәрігер пациент туралы көптеген ақпаратты талдайды: шағымдарын, ауру анамнезін, зертханалық және аспаптық зерттеулер нәтижелерін, қатар жүретін аурулары мен қабылдап жүрген дәрілік препараттары туралы мәліметтерді.

Интеллектуалды жүйелер осы мәліметтерді біріктіріп, талдауға, белгілі бір қауіп факторларын анықтауға және қолайсыз жағдайлардың даму ықтималдығын бағалауға көмектесе алады. Өңделген деректер негізінде алгоритмдер қосымша ұсынымдар қалыптастырып, оларды медицина маманы әрі қарайғы тексеру тактикасын анықтау кезінде пайдалана алады.

Мысалы, электрондық медициналық картаны талдау кезінде жүйе бірнеше қауіп факторының қатар кездесуіне назар аударуы немесе зертханалық көрсеткіштердің динамикасындағы өзгерістерді анықтауы мүмкін. Бұл дәрігерге үлкен көлемдегі ақпаратты

жылдам бағдарлауға және пациенттің жағдайын бағалау кезінде қосымша мәліметтерді ескеруге көмектеседі.

Алайда мұндай жүйелер маманның қатысуынсыз түпкілікті диагноз қоймауы немесе ем тағайындамауы тиіс. Клиникалық шешім пациенттің жағдайын, ағзасының жеке ерекшеліктерін, анамнезін және тексеру нәтижелерін кешенді талдауды талап етеді.

Дербестендірілген медицина және жасанды интеллект

Дербестендірілген медицина – заманауи медициналық технологияларды дамытудың тағы бір перспективалы бағыты. Оның негізгі мақсаты – профилактикалық және емдік іс-шараларды таңдаған кезде пациенттің жеке ерекшеліктерін ескеру.

Емдеудің дәстүрлі тәсілдері көбінесе жалпы клиникалық ұсынымдарға негізделеді, алайда әртүрлі пациенттердің бірдей емдеу әдістеріне реакциясы өзгеше болуы мүмкін. Емнің тиімділігіне жас, тұқым қуалаушылық, қатар жүретін аурулар, зат алмасу ерекшеліктері және басқа да факторлар әсер етуі ықтимал.

Машиналық оқыту алгоритмдері клиникалық, генетикалық және зертханалық деректерді талдауға, емдеу нәтижелерін салыстыруға және ғылыми зерттеулерде пайдалы болуы мүмкін заңдылықтарды анықтауға мүмкіндік береді. Мұндай технологияларды пайдалану пациенттердің жеке ерекшеліктерін тереңірек зерттеуге және медициналық көмек көрсету тәсілдерін жетілдіруге жол ашады.

Сонымен қатар жасанды интеллект дәрілік препараттарды әзірлеу кезінде қолданылады. Компьютерлік модельдер молекулалық құрылымдарды зерттеуге, әртүрлі қосылыстардың өзара әрекеттесуін талдауға және әрі қарай зерттеуге перспективалы заттарды анықтауға көмектесе алады. Бұл ғылыми-зерттеу жұмысының жекелеген кезеңдерін оңтайландыруға ықпал етуі мүмкін.

Сонымен бірге компьютерлік модельдеу нәтижелері жаңа препаратты қолдануға жеткілікті негіз болып саналмайды. Алынған деректер кейінгі зертханалық, клиникаға дейінгі және клиникалық тексерулерден өтуі тиіс. Осылайша, жасанды интеллект медициналық және фармакологиялық зерттеулердің дәстүрлі әдістерін толықтыратын көмекші құрал ретінде қызмет етеді [4].

Медициналық үдерістерді автоматтандыру

Жасанды интеллектіні қолдану ауруларды диагностикалау және емдеумен ғана шектелмейді. Медициналық мекемелердің әкімшілік және ұйымдастырушылық үдерістерін автоматтандыру саласында да айтарлықтай мүмкіндіктер бар.

Заманауи интеллектуалды жүйелер медициналық мәтіндерді өңдей алады, жазбаларды құрылымдайды, қорытындылардың бастапқы нұсқаларын жасайды және электрондық медициналық карталардан қажетті ақпаратты бөліп алады. Мұндай технологиялар медициналық құжаттаманы дайындау, зерттеу нәтижелерін жүйелеу және пациент туралы ақпаратты іздеу үшін пайдаланылуы мүмкін.

Күнделікті қайталанатын міндеттерді автоматтандыру медицина қызметкерлерінің уақыт шығынын азайтуға мүмкіндік береді. Нәтижесінде мамандар пациенттермен тікелей қарым-қатынасқа, тексерулер жүргізуге және ем нәтижелерін бағалауға көбірек көңіл бөле алады.

Медициналық ұйымдарды басқаруда жасанды интеллект алгоритмдері бөлімшелерге түсетін жүктемені талдау, қабылдау кестесін жоспарлау, медициналық жабдыққа қажеттілікті болжау және ресурстарды тиімді бөлу үшін қолданылуы мүмкін. Қоғамдық денсаулық сақтау саласында машиналық оқыту әдістері эпидемиологиялық деректерді талдау, сырқаттанушылық динамикасын зерттеу және белгілі бір үрдістерді анықтау үшін пайдаланылуы ықтимал.

Жеке бағыттардың бірі медициналық ақпаратты өңдеу үшін тілдік модельдерді қолданумен байланысты. Мұндай жүйелер құжаттардың бастапқы нұсқаларын жасауға,

мәтіндік деректерді қорытындылауға және әртүрлі дереккөздерден алынған мәліметтерді жүйелеуге көмектесе алады. Алайда автоматты түрде жасалған мәтіндер мен ұсынымдарды медицина маманы міндетті түрде тексеруі тиіс. Тілдік модельдер фактілік қателер жіберуі, ақпаратты дұрыс түсіндірмеуі немесе бастапқы деректермен расталмаған қорытындылар жасауы мүмкін.

Сондықтан медициналық үдерістерді автоматтандыру кәсіби бақылау мен мамандардың жауапкершілігін сақтай отырып жүзеге асырылуы керек.

Медицинадағы нейрондық желі технологияларының артықшылықтары

Жасанды интеллектіні пайдалану денсаулық сақтау жүйесін жетілдіруге бірқатар мүмкіндік береді. Негізгі артықшылықтарының бірі – ақпаратты өңдеудің жоғары жылдамдығы. Компьютерлік алгоритмдер үлкен көлемдегі деректерді салыстырмалы түрде қысқа уақыт ішінде талдай алады, бұл әсіресе медициналық кескіндермен және электрондық медициналық карталармен жұмыс істеу кезінде маңызды.

Тағы бір артықшылығы – медициналық ақпараттың күрделі жиынтықтарындағы заңдылықтарды анықтау мүмкіндігі. Нейрондық желілер көптеген мысалдар негізінде оқытылып, деректерді алдын ала жіктеу мен талдау үшін қолданылатын белгілі бір белгілерді тани алады.

ЖИ қолданудың негізгі артықшылықтарына мыналар жатады:

– медициналық кескіндер мен зерттеу нәтижелерін өңдеуді жеделдету;

– қайталанатын міндеттерді және медициналық құжаттаманың жекелеген үдерістерін автоматтандыру;

– клиникалық ақпараттың үлкен көлемін талдау мүмкіндігі;

– диагностикалық маңызы бар белгілерді анықтауға қолдау көрсету;

– қауіп факторларын бағалауға және жекелеген жағдайларды болжауға көмектесу;

кейбір диагностикалық және ұйымдастырушылық үдерістерді стандарттау деңгейін арттыру.

Интеллектуалды технологияларды дұрыс енгізу медициналық ұйымдар жұмысының тиімділігін арттыруға және қолда бар ресурстарды ұтымды пайдалануға ықпал етуі мүмкін. Бұл ретте олардың практикалық пайдасы алгоритмдердің сапасына, пайдалану жағдайларына және медицина қызметкерлерінің дайындық деңгейіне байланысты.

Жасанды интеллектіні қолданудың шектеулері мен мәселелері

Елеулі перспективаларына қарамастан, медицинада жасанды интеллектіні пайдалану бірқатар шектеулермен қатар жүреді. Негізгі мәселелердің бірі – алгоритм сапасының оқыту деректеріне тәуелділігі. Сенімді нәтижелер алу үшін нейрондық желілер жеткілікті көлемдегі, сапалы және репрезентативті ақпарат массивтері негізінде оқытылуы тиіс.

Егер пациенттердің белгілі бір топтары оқыту іріктемесінде жеткіліксіз қамтылса, алгоритмнің сол топтар үшін жұмыс дәлдігі төмендеуі мүмкін. Бұл жүйені оқыту кезінде пайдаланылған деректерден ерекшеленетін сипаттамалары бар пациенттерге қолданғанда нәтижелердің сенімділігі төмендеу қаупін туғызады.

Тағы бір мәселе – қате болжамдар жасау және нәтижелерді дұрыс түсіндірмеу ықтималдығы. Тіпті заманауи алгоритмдер де абсолютті дәлдікке кепілдік бере алмайды. Жүйе патологиялық өзгерістерді байқамай қалуы, аурудың бар-жоғын қате анықтауы немесе клиникалық жағдайға сәйкес келмейтін ұсыным қалыптастыруы мүмкін.

Сонымен қатар кейбір нейрондық модельдердің түсіндірмелілігі жеткіліксіз. Бұл маманға жүйенің белгілі бір нәтижені нақты қандай белгілер негізінде қалыптастырғанын анықтауды қиындатады. Медициналық практикада бұл мәселенің маңызы ерекше, өйткені диагностикалық және емдік шешімдер пациенттердің денсаулығы мен қауіпсіздігіне тікелей байланысты.

Жеке ақпаратты қорғау да маңызды мәселе болып қала береді. Медициналық

деректер құпия ақпаратқа жатады, сондықтан оларды жинау, сақтау және өңдеу заңнама талаптарына сәйкес жүзеге асырылуы тиіс. Интеллектуалды жүйелерді енгізу кезінде электрондық медициналық карталарды, тексеру нәтижелерін және пациенттер туралы басқа мәліметтерді қорғауды қамтамасыз ету қажет.

Этикалық аспектілерге де ерекше назар аудару керек. Жасанды интеллектіні пайдалану пациенттердің құқықтарын шектеуге, медициналық көмектің қолжетімділігін төмендетуге немесе халықтың жекелеген топтарын кемсітуге әкелмеуі тиіс. Дүниежүзілік денсаулық сақтау ұйымы денсаулық сақтау саласында интеллектуалды жүйелерді әзірлеу және енгізу кезінде ашықтықты, қауіпсіздікті, жауапкершілікті және әділдікті қамтамасыз ету қажеттігін атап көрсетеді [3].

Осылайша, жасанды интеллектіні тиімді қолдану алгоритмдерді тәуелсіз тексеруді, олардың жұмыс сапасын тұрақты бақылауды, медицина қызметкерлерін оқытуды және дербес деректерді қорғау қағидаттарын сақтауды талап етеді.

Қазақстанның денсаулық сақтау саласында жасанды интеллектіні дамытудың перспективалары

Қазақстан Республикасы үшін жасанды интеллектіні енгізу денсаулық сақтауды цифрландыру және заманауи диагностикалық технологияларды дамыту тұрғысынан үлкен қызығушылық тудырады. Интеллектуалды жүйелерді пайдалану медициналық ұйымдардың жұмысын жетілдіруге, диагностикалық кескіндерді өңдеу тиімділігін арттыруға және медициналық құжаттаманы автоматтандыруға ықпал етуі мүмкін.

Мұндай технологияларды қолдану диагностикалық бөлімшелер, зертханалар және үлкен көлемдегі ақпаратпен жұмыс істейтін медициналық ұйымдар үшін ерекше маңызды болуы ықтимал. Интеллектуалды алгоритмдер зерттеу нәтижелерін талдау кезінде қосымша құрал ретінде қызмет етіп, медицина мамандарына деректерді жүйелеуге көмектесе алады.

Бұл ретте ұлттық денсаулық сақтау жүйесінің ерекшеліктерін ескеру қажет. Оларға заманауи жабдықтардың қолжетімділігі, медициналық ақпараттық жүйелердің сапасы, цифрлық инфрақұрылым деңгейі және медициналық құжаттаманың тілдік әртүрлілігі жатады. Жасанды интеллектіні тиімді қолдану үшін пайдаланылатын алгоритмдер жергілікті медициналық практиканың ерекшеліктерін ескеруі маңызды.

Интеллектуалды жүйелерді кеңінен енгізбес бұрын олар Қазақстанның медициналық ұйымдарындағы жұмыс жағдайларына сәйкес келетін деректер негізінде тексерілуі тиіс. Бұл олардың нақты клиникалық жағдайларда дәлдігін, сенімділігін және практикалық қолдануға жарамдылығын бағалауға мүмкіндік береді.

Медицина қызметкерлерін даярлау да маңызды бағыттардың бірі болып табылады. Заманауи маман кәсіби медициналық біліммен қатар цифрлық технологиялардың жұмыс істеу қағидаттарын, жасанды интеллектінің мүмкіндіктері мен автоматтандырылған талдаудың шектеулерін түсінуі керек.

Медициналық білім беру саласында заманауи ақпараттық жүйелерді, деректерді өңдеу негіздерін және интеллектуалды технологияларды қауіпсіз пайдалану қағидаттарын зерделеуге де көңіл бөлген жөн. Бұл болашақ мамандарға кәсіби қызметінде цифрлық құралдармен тиімді жұмыс істеуге мүмкіндік береді.

Осылайша, Қазақстанның денсаулық сақтау жүйесін дамытудың перспективалы бағыты – ғылыми негізділікке, клиникалық тексеруге және кәсіби бақылауға сүйене отырып жасанды интеллектіні енгізу.

Жасанды интеллектті қолдану кезіндегі дәрігердің рөлі

Интеллектуалды технологиялардың дамуына қарамастан, диагностика және емдеу үдерісіндегі жетекші рөл медицина маманында қалуы тиіс. Жасанды интеллект жекелеген аналитикалық міндеттерді орындап, ақпаратты өңдеп, клиникалық жағдайды бағалаудың қосымша нұсқаларын ұсына алады, алайда ол пациенттің жеке ерекшеліктерін толыққанды

түсіне алмайды.

Дәрігердің жұмысы тек зерттеу нәтижелерін талдаумен шектелмейді. Ол пациентпен қарым-қатынас жасауды, шағымдарын бағалауды, анамнезін зерделеуді, физикалық тексеру жүргізуді және көптеген факторларды ескере отырып шешім қабылдауды қамтиды. Кейбір клиникалық жағдайлар автоматтандырылған деректерді өңдеу арқылы толық алмастыру мүмкін емес жеке тәсілді талап етеді.

Сондықтан жасанды интеллектіні пайдаланудың ең тиімді моделі – медицина маманы мен интеллектуалды жүйенің ынтымақтастығы. Алгоритм қосалқы аналитикалық міндеттерді орындайды, ал дәрігер алынған нәтижелерді бағалап, оларды клиникалық деректермен салыстырады және түпкілікті шешім қабылдайды.

Мұндай тәсіл кәсіби медицина қызметкерінің жауапкершілігі мен пациент қауіпсіздігін сақтай отырып, заманауи технологиялардың артықшылықтарын пайдалануға мүмкіндік береді. Болашақта адам мен жасанды интеллектінің өзара әрекеттестігі цифрлық медицинаны дамытудың негізгі бағыттарының біріне айналуы мүмкін [4].

Қорытынды

Жасанды интеллект пен нейрондық желі технологиялары қазіргі медицинаны дамытудың маңызды бағыттарының бірі болып табылады. Оларды қолдану ауруларды диагностикалауды жетілдіруге, медициналық кескіндерді талдауға, клиникалық шешімдерді қолдауға, емдеуді жекелендіруге және медициналық үдерістерді автоматтандыруға қосымша мүмкіндіктер ашады.

Интеллектуалды жүйелерді қолданудың ең перспективалы салаларына сәулелік диагностика, ультрадыбыстық зерттеулер, электрокардиограммаларды өңдеу, зертханалық және клиникалық деректерді талдау, сондай-ақ белгілі бір қауіп факторларын болжау жатады. Нейрондық желілерді пайдалану ақпаратты өңдеуді жеделдетуге, жекелеген үдерістерді стандарттауға және медицина персоналы жұмысының тиімділігін арттыруға ықпал етуі мүмкін.

Сонымен бірге интеллектуалды жүйелердің практикалық пайдасы оқыту деректерінің сапасына, алгоритмдердің дәлдігіне, оларды қолдану жағдайларына және клиникалық бақылауды ұйымдастыруға байланысты. Жеке ақпаратты қорғау, бағдарламалық жүйелер жұмысының нәтижелерін тексеру және этикалық қағидаттарды сақтау ерекше маңызға ие.

Жасанды интеллект дәрігерді толық алмастыратын құрал ретінде қарастырылмауы тиіс, өйткені диагноз қою және емдеу тактикасын таңдау пациенттің жағдайын, оның жеке ерекшеліктері мен клиникалық жағдайды кешенді бағалауды талап етеді.

Демек, ғылыми дәлелдерге, клиникалық тексеруге және кәсіби бақылауға негізделген нейрондық желі технологияларын жауапкершілікпен енгізу медициналық көмектің сапасын арттырудың және цифрлық денсаулық сақтауды одан әрі дамытудың маңызды шарттарының бірі бола алады. Ең перспективалы тәсіл – жасанды интеллект сенімді көмекші құрал ретінде қолданылып, шешім қабылдауда медицина маманы жетекші рөлін сақтайтын модель.

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COMPARATIVE MECHANISMS OF HYPOXIA SURVIVAL IN HUMAN TISSUES AND OTHER ORGANISMS

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1. Abstract and scope

Hypoxia is a reduction in oxygen availability relative to cellular demand. It is not a uniform insult: oxygen tension, duration, intermittency, temperature, nutrient supply, workload, and reoxygenation determine whether cells adapt, become dysfunctional, or die. This review compares human tissues with naturally hypoxia-tolerant organisms, emphasizing molecular mechanisms rather than treating all low-oxygen states as equivalent. (Lee et al., 2020; Semenza, 2012)

The central argument is that survival emerges from coordinated control of oxygen sensing, ATP demand, substrate use, redox balance, ion homeostasis, protein synthesis, vascular supply, and cell fate. In most mammalian cells, oxygen-dependent prolyl hydroxylases regulate hypoxia-inducible factor alpha (HIF-α). When oxygen is sufficient, hydroxylated HIF-α is recognized by von Hippel–Lindau protein and degraded by the proteasome. (Kaelin & Ratcliffe, 2008; Lee et al., 2020) During hypoxia, hydroxylation falls, HIF-α accumulates, dimerizes with HIF-1β, and activates genes involved in glycolysis, angiogenesis, erythropoiesis, iron handling, and survival. Yet HIF signaling is only one layer. AMPK, mTOR, unfolded-protein responses, autophagy, mitochondrial remodeling, nitric oxide, and microRNAs shape tissue-specific outcomes. (Semenza, 2012; Jiang et al., 2021)

Human brain, heart, kidney, liver, skeletal muscle, placenta, and vascular endothelium face different oxygen landscapes and have distinct energetic priorities. The brain requires continuous ATP to maintain ion gradients and synaptic activity; the kidney medulla operates physiologically at low oxygen; the placenta develops along steep oxygen gradients; and skeletal muscle experiences repeated local hypoxia during contraction. In contrast, turtles, crucian carp, diving mammals, and naked mole-rats have evolved systemic and cellular strategies that permit survival under oxygen levels that would injure most humans. (Jiang et al., 2021; Burton et al., 2021)

This is a narrative comparative review, not a systematic review or meta-analysis. It synthesizes established mechanisms and selected PubMed-indexed studies. Evidence from animal models is distinguished from direct human evidence, and mechanistic hypotheses are not presented as proven therapies. (Lee et al., 2020)

The comparison highlights both shared biochemical modules and evolutionary innovations, including profound metabolic depression, ion-channel suppression, antioxidant preparedness, and fructose-supported glycolysis. These principles may inform future approaches to ischemia,

stroke, myocardial infarction, organ preservation, and critical illness, but translation requires careful attention to species differences and the hazards of reoxygenation. Importantly, oxygen tension should be interpreted alongside perfusion, substrate availability, temperature, and metabolic workload. (Larson et al., 2014; Park et al., 2017)

Measurements from whole tissue can conceal opposing responses among epithelial, stromal, immune, and vascular populations. An adaptive molecular signature does not necessarily demonstrate improved survival; functional recovery remains the decisive endpoint. Responses are shaped by exposure duration, oxygen cycling, developmental stage, sex, nutrition, and prior physiological conditioning.

Reoxygenation experiments should therefore reproduce clinically relevant timing and measure both early injury and delayed recovery. Comparative evidence is strongest when molecular observations are paired with physiological measurements and perturbation of candidate pathways.

Keywords: Hypoxia; anoxia tolerance; comparative physiology; hypoxia-inducible factor (HIF); tissue-specific adaptation; metabolic depression; mitochondrial adaptation; reoxygenation injury.

2. Oxygen availability and the cellular problem

Oxygen reaches cells through a cascade: atmospheric partial pressure, alveolar ventilation, pulmonary diffusion, hemoglobin loading, cardiac output, microvascular distribution, diffusion through interstitium, and mitochondrial consumption. Failure at any level can create tissue hypoxia. High altitude lowers inspired oxygen pressure, whereas anemia lowers oxygen-carrying capacity, ischemia restricts blood flow, and respiratory disease impairs gas exchange. (Brezis & Rosen, 1995; Lee et al., 2020)

These conditions may produce similar intracellular oxygen deficits but differ in carbon dioxide, pH, nutrients, hormones, and waste removal. At the cellular level, oxygen serves as the terminal electron acceptor of the mitochondrial respiratory chain. Complex IV reduces oxygen to water, allowing electron flow, proton pumping, and ATP synthesis.

When oxygen becomes limiting, oxidative phosphorylation slows, NADH oxidation is constrained, and ATP generation increasingly depends on substrate-level phosphorylation. The challenge is not simply a lack of fuel: glycolysis yields far less ATP per glucose than complete oxidation, while lactate accumulation and associated acid–base disturbances may develop when production exceeds clearance. Cells must therefore reduce ATP demand, preserve essential gradients, and selectively maintain biosynthesis.

The severity of hypoxia is context dependent. A moderate fall in oxygen can activate adaptive transcription without collapsing ATP levels. Severe ischemia, by contrast, combines oxygen deprivation with inadequate glucose delivery and impaired metabolite clearance. (Hausenloy & Yellon, 2013; Hausenloy & Yellon, 2016)

Reperfusion restores oxygen but can provoke reactive oxygen species, calcium overload, inflammation, and mitochondrial permeability transition. Thus, survival requires not only tolerating low oxygen but also managing the transition back to oxygenated metabolism. Oxygen gradients are normal features of many tissues.

The renal medulla, intestinal mucosa, bone marrow niches, and developing placenta contain physiologically low-oxygen regions. Stem cells may use these niches to limit differentiation and oxidative stress. A low oxygen value is therefore not synonymous with pathology. (Brezis & Rosen, 1995; Colgan & Taylor, 2010; Burton et al., 2021)

The relevant variable is the relationship between local oxygen supply and cellular demand, interpreted in the context of the tissue's evolved operating range. Comparative physiology adds an important distinction between hypoxia and anoxia. Hypoxia means reduced oxygen; anoxia means near-complete absence.

Many mammals tolerate hypoxia transiently but cannot sustain ATP-dependent function during prolonged anoxia. Some ectothermic vertebrates survive anoxia by suppressing metabolism dramatically, while naked mole-rats can transiently use unusual anaerobic fuels. These organisms reveal that oxygen dependence is biologically adjustable, but only within limits imposed by temperature, energy stores, and the capacity to suppress expensive functions (Storey, 2007; Park et al., 2017) (Fig.1).

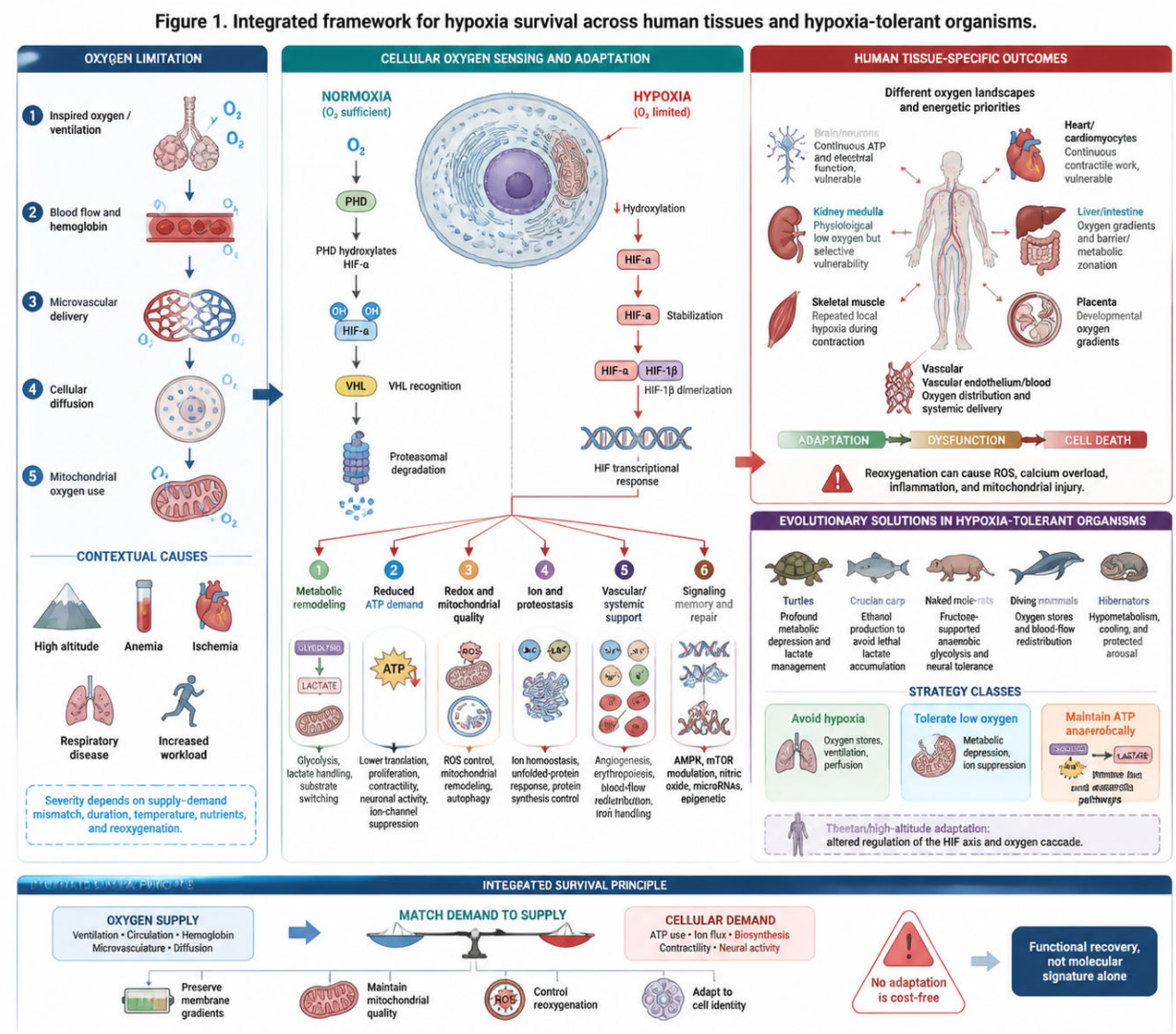


Figure 1. Integrated framework for hypoxia survival across human tissues and hypoxia-tolerant organisms.

Hypoxia survival is determined by the interaction between oxygen supply, cellular oxygen demand, tissue identity, exposure conditions, and the capacity to manage reoxygenation. The left panel illustrates the oxygen-delivery cascade from inspired oxygen and ventilation through blood flow, hemoglobin-mediated transport, microvascular distribution, cellular diffusion, and mitochondrial oxygen utilization. Hypoxia may arise from high altitude, anemia, ischemia, respiratory disease, or increased metabolic workload, and its severity depends on the magnitude and duration of the supply–demand mismatch, as well as temperature, nutrient availability, and reoxygenation.

The central panel contrasts normoxic and hypoxic oxygen sensing. Under normoxia, prolyl hydroxylase domain enzymes hydroxylate hypoxia-inducible factor alpha (HIF-α), enabling von Hippel–Lindau (VHL)-dependent recognition and proteasomal degradation. Under hypoxia, reduced hydroxylation stabilizes HIF-α, permitting dimerization with HIF-1β and activation of hypoxia-responsive transcription. HIF signaling integrates with metabolic remodeling, reduced ATP demand, redox and mitochondrial quality control, ion and proteostasis regulation, vascular and systemic support, and signaling pathways involved in memory and repair.

The upper-right panel summarizes tissue-specific outcomes in the human brain, heart, kidney, liver and intestine, skeletal muscle, placenta, and vascular system. Because these tissues operate within distinct oxygen landscapes and have different energetic priorities, hypoxia may result in adaptation, dysfunction, or cell death. Reoxygenation represents a second injury phase that may involve reactive oxygen species generation, calcium overload, inflammation, and mitochondrial damage.

The lower-right panel presents evolutionary solutions in hypoxia-tolerant organisms, including metabolic depression and lactate management in turtles, ethanol production in crucian carp, fructose-supported anaerobic glycolysis in naked mole-rats, oxygen storage and blood-flow redistribution in diving mammals, and hypometabolism with temperature reduction in hibernators. The bottom panel emphasizes the overarching principle of matching cellular demand to oxygen supply while preserving membrane gradients, maintaining mitochondrial quality, controlling reoxygenation, and accounting for cell identity. These adaptations are mechanistically diverse and involve trade-offs; therefore, functional recovery rather than an isolated molecular signature remains the decisive outcome. Representative mechanisms are synthesized from the accompanying review and prior work on hypoxia signaling, tissue adaptation, and comparative physiology

3. Canonical oxygen sensing: PHD–VHL–HIF

The best characterized mammalian oxygen sensor is the prolyl hydroxylase domain protein–von Hippel–Lindau–hypoxia-inducible factor pathway. PHD1, PHD2, and PHD3 are 2-oxoglutarate-dependent dioxygenases that use molecular oxygen, ferrous iron, and 2-oxoglutarate to hydroxylate specific proline residues on HIF-α. Hydroxylated HIF-α binds the VHL E3 ubiquitin ligase complex, becomes polyubiquitylated, and is degraded by the proteasome. (Kaelin & Ratcliffe, 2008; Lee et al., 2020)

Because hydroxylation requires oxygen, PHD activity falls as oxygen becomes limiting and HIF-α protein accumulates. HIF-1α and HIF-2α share HIF-1β, also called ARNT, but have partly distinct expression patterns and target programs. HIF-1α often drives acute metabolic adaptation, including glucose transporters and glycolytic enzymes. (Semenza, 2012; Jiang et al., 2021)

HIF-2α is prominent in selected cell populations, including renal erythropoietin-producing interstitial cells and some endothelial and parenchymal cells, where it contributes to erythropoietin regulation and vascular biology. HIF-3α comprises multiple isoforms that can modulate HIF signaling. The outcome depends on cell identity, chromatin accessibility, coactivators, oxygen history, and the balance of HIF isoforms. (Lee et al., 2020; Semenza, 2012)

A second oxygen-dependent modification is asparaginyl hydroxylation by factor inhibiting HIF (FIH), which limits recruitment of transcriptional coactivators such as p300/CBP. FIH and PHD enzymes have different oxygen sensitivities, creating a graded response rather than a binary switch. Metabolites also influence the pathway. (Kaelin & Ratcliffe, 2008; Lee et al., 2020)

Succinate and fumarate can inhibit 2-oxoglutarate-dependent enzymes when they accumulate, while iron availability, reactive oxygen species, nitric oxide, and inflammatory signaling modify HIF stability or activity. HIF target genes include SLC2A1/GLUT1, glycolytic enzymes, lactate dehydrogenase A, pyruvate dehydrogenase kinase 1, vascular endothelial growth factor, erythropoietin, and enzymes of pH regulation. PDK1 inhibits pyruvate dehydrogenase, restricting pyruvate entry into the tricarboxylic acid cycle. (Lee et al., 2020)

This reduces mitochondrial oxygen demand and can limit electron leakage, although it also constrains oxidative ATP production. VEGF supports vascular remodeling, while EPO increases red-cell production through erythroid progenitors. HIF activation is adaptive only within a suitable range.

Excessive or prolonged signaling can promote pulmonary hypertension, erythrocytosis, fibrosis, tumor progression, or maladaptive vascular remodeling. Conversely, insufficient signaling can impair oxygen delivery and tissue repair. Human high-altitude adaptation illustrates this balance: variants in EPAS1 and EGLN1 alter the HIF axis and can limit excessive hemoglobin elevation. (Lorenzo et al., 2014; Petousi & Robbins, 2014)

Oxygen sensing is therefore a control system whose benefit depends on tissue, dose, and time. Importantly, oxygen tension should be interpreted alongside perfusion, substrate availability, temperature, and metabolic workload. Measurements from whole tissue can conceal opposing responses among epithelial, stromal, immune, and vascular populations.

4. Mitochondria, redox balance, and metabolic remodeling

Mitochondria are both oxygen consumers and signaling platforms. Under oxygen limitation, electron transport becomes constrained, the NADH/NAD+ ratio rises, and mitochondrial membrane potential may change. Depending on substrate supply and respiratory-chain state, mitochondria can generate signaling reactive oxygen species, particularly at complex III. (Lee et al., 2020; Chandel et al., 2000)

These oxidants can influence HIF stabilization, phosphatases, kinases, and inflammatory pathways. However, reactive oxygen species are not uniformly harmful: low, localized signals participate in adaptation, whereas excessive oxidation damages lipids, proteins, DNA, and mitochondrial membranes. A common adaptive response is to reduce mitochondrial oxygen consumption. (Chandel et al., 2000)

HIF-induced PDK1 inhibits pyruvate dehydrogenase, shifting pyruvate away from acetyl-CoA formation and toward lactate. HIF can also induce enzymes that support glycolysis and lactate export. Mitochondrial content, cristae structure, respiratory-chain composition, and substrate preference may be remodeled. (Lee et al., 2020)

Mitophagy, mediated through pathways including PINK1–Parkin and receptor proteins such as BNIP3 and NIX, removes damaged mitochondria. This quality-control response can reduce oxidant production, but excessive mitophagy risks depleting the organelle pool needed for recovery. AMP-activated protein kinase (AMPK) senses cellular energy stress through changes in adenine nucleotide ratios and upstream kinases. (Lee et al., 2020)

AMPK suppresses energy-consuming anabolic processes and can promote glucose uptake, fatty-acid oxidation when oxygen permits, and autophagy. In parallel, mTOR complex 1 integrates amino acids, growth factors, and energy status. Hypoxia can inhibit mTORC1 through REDD1, AMPK, and other mechanisms, reducing protein synthesis and conserving ATP. (Lee et al., 2020)

The integrated effect is a shift from growth toward maintenance. Redox defense includes glutathione, thioredoxin, superoxide dismutases, catalase, peroxiredoxins, and NRF2-regulated genes. Cells also limit iron-catalyzed radical chemistry by controlling labile iron and ferritin.

During reoxygenation, antioxidant capacity becomes especially important because rapid oxygen restoration can produce a burst of reactive oxygen species. The magnitude of injury depends on prior hypoxic duration, mitochondrial integrity, calcium loading, and inflammatory cell recruitment. Different tissues tune these mechanisms differently. (Hausenloy & Yellon, 2013)

Skeletal muscle can remodel mitochondria and tolerate repeated transient oxygen deficits. Neurons have limited glycolytic reserve and high ATP demand, so even modest mitochondrial failure can disrupt membrane potential. Renal medullary cells already function at low oxygen and rely partly on glycolytic metabolism.

The adaptive objective is not to eliminate mitochondrial respiration, but to match oxygen consumption to available supply while retaining sufficient capacity for recovery. Importantly, oxygen tension should be interpreted alongside perfusion, substrate availability, temperature, and metabolic workload. Measurements from whole tissue can conceal opposing responses among epithelial, stromal, immune, and vascular populations (Fig. 2).

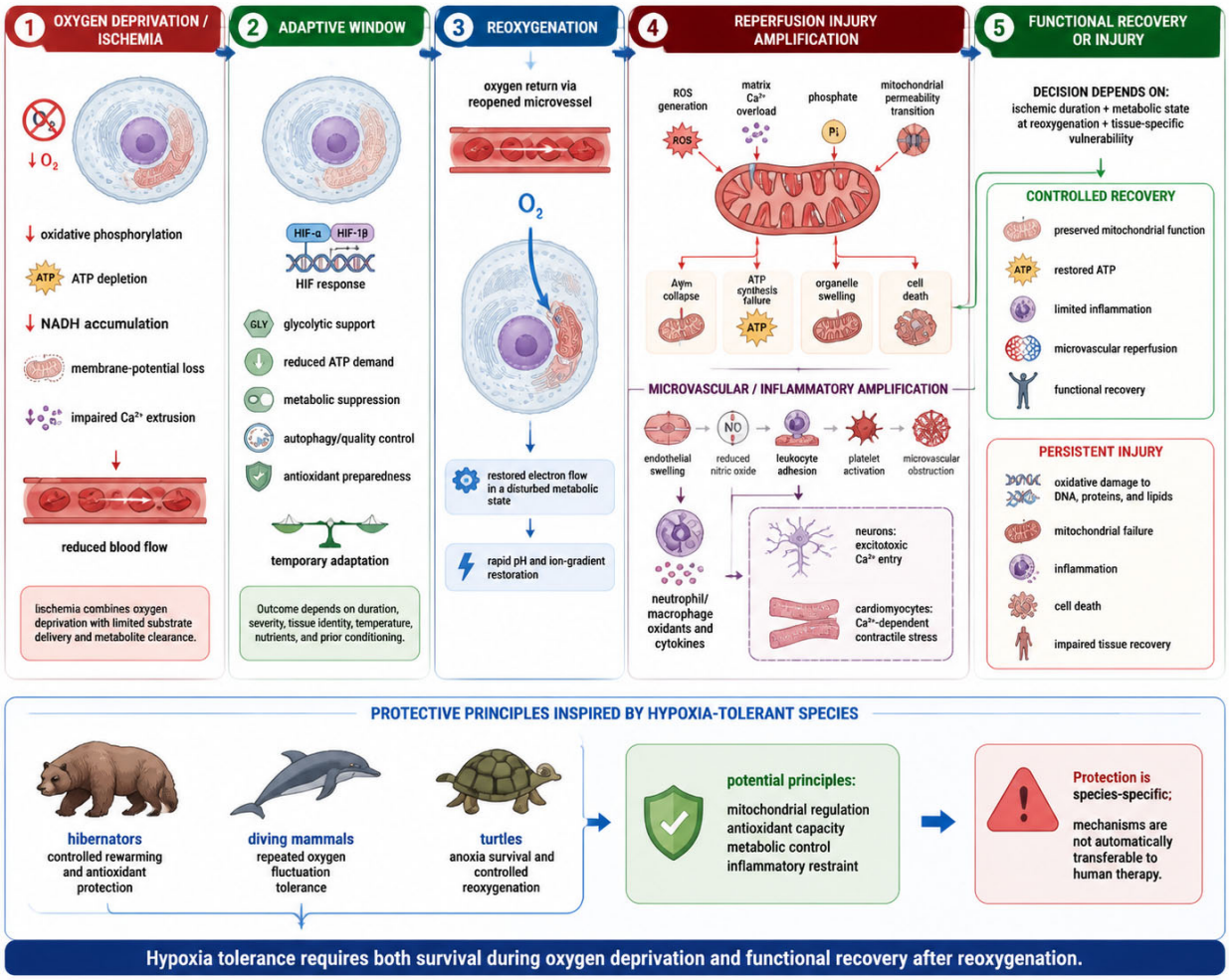


Figure 2. Hypoxia–reoxygenation as a two-phase determinant of cellular survival and functional recovery.

The figure illustrates the sequential cellular events that determine whether oxygen deprivation is followed by adaptation, reperfusion injury, or functional recovery. During oxygen deprivation or ischemia, reduced oxygen availability limits oxidative phosphorylation and promotes ATP depletion, NADH accumulation, loss of mitochondrial membrane potential, impaired calcium extrusion, and reduced blood flow. The severity of this initial injury is influenced by the extent and duration of ischemia, substrate availability, metabolic demand, tissue identity, temperature, and prior conditioning.

Within a temporary adaptive window, hypoxia-inducible factor signaling and associated responses support glycolytic ATP production, suppress energy-intensive processes, promote metabolic depression, maintain autophagy and organelle quality control, and enhance antioxidant preparedness. These responses may preserve cellular viability when the duration and severity of oxygen limitation remain within the tissue's adaptive capacity.

Reoxygenation restores oxygen delivery and electron flow but occurs in a metabolically disturbed cellular environment. The resulting increase in reactive oxygen species, together with matrix calcium accumulation, phosphate excess, and mitochondrial permeability transition, can cause mitochondrial membrane-potential collapse, failure of ATP synthesis, organelle swelling, and cell death. Reperfusion injury is further amplified by endothelial swelling, reduced nitric oxide bioavailability, leukocyte adhesion, platelet activation, microvascular obstruction, and inflammatory mediator release. Neurons and cardiomyocytes are particularly vulnerable because of excitotoxic calcium entry and calcium-dependent contractile stress, respectively.

The final outcome depends on ischemic duration, the metabolic state at reoxygenation, and tissue-specific vulnerability. Controlled recovery is associated with preserved mitochondrial function, restored ATP production, limited inflammation, microvascular reperfusion, and functional recovery; persistent injury is associated with oxidative damage, mitochondrial failure, inflammation, cell death, and impaired tissue repair. The lower panel summarizes potentially protective principles observed in hibernators, diving mammals, and turtles, while emphasizing that these mechanisms are species-specific and cannot be assumed to translate directly to human therapy. Thus, hypoxia tolerance should be defined by both survival during oxygen deprivation and functional recovery after reoxygenation

5. Brain and neurons: protecting electrical function

The mammalian brain is highly vulnerable to oxygen deprivation because neurons maintain steep sodium, potassium, and calcium gradients and sustain energetically expensive synaptic transmission. Na+/K+-ATPase activity consumes a large fraction of neuronal ATP. When ATP falls, membrane depolarization develops, glutamate release increases, and glutamate receptor activation permits calcium influx. (Larson et al., 2014)

Calcium activates proteases, phospholipases, endonucleases, and nitric oxide synthase, while mitochondrial calcium loading can trigger permeability transition and cell death. Ischemic injury is therefore an interaction between energy failure and excitotoxic signaling. HIF signaling can promote neuronal adaptation by increasing glucose transport, glycolytic capacity, vascular support, and survival-associated pathways. (Larson et al., 2014)

Astrocytes are more glycolytically flexible than neurons and can provide metabolic support through lactate shuttling. Astrocytes also regulate extracellular potassium, glutamate uptake, water balance, and blood–brain barrier function. Endothelial cells and pericytes influence cerebral perfusion and barrier integrity. (Larson et al., 2014)

The brain response is thus multicellular: neurons, astrocytes, microglia, oligodendrocytes, and vascular cells contribute distinct functions. Yet HIF alone cannot explain survival. A critical protective strategy is suppression of neuronal activity and ion flux.

Lowering synaptic transmission reduces ATP demand and delays anoxic depolarization. Hypoxia-tolerant vertebrates show unusually strong control of excitability, neurotransmitter release, and ion-channel function. In turtles, adenosine signaling contributes to coordinated reductions in neuronal activity, while enhanced inhibitory tone and reduced excitatory drive protect ionic homeostasis. (Larson et al., 2014; Storey, 2007)

Such mechanisms preserve ATP for essential maintenance rather than high-frequency computation. Naked mole-rat brain tissue displays remarkable tolerance compared with typical rodents. Hippocampal slices maintain synaptic function longer during oxygen deprivation and can recover after prolonged anoxia. (Larson et al., 2014; Park et al., 2017)

This phenotype is associated with intrinsic neural adaptations and a capacity for profound metabolic suppression. During anoxia, naked mole-rats can use fructose-driven glycolysis, involving high expression of GLUT5 and ketohexokinase, bypassing the phosphofructokinase control point that constrains conventional glucose glycolysis. The mechanism is striking but should not be generalized to humans, whose brain does not possess equivalent systemic fructose-based anoxia tolerance. (Larson & Park, 2009; Park et al., 2017)

Reoxygenation adds a second injury phase. Restored perfusion can generate oxidants, activate microglia, disrupt the blood–brain barrier, and initiate delayed neuronal death. Therapeutic strategies inspired by tolerant species may include transiently reducing excitability, stabilizing ion gradients, supporting astrocytic metabolism, and controlling oxidative stress. (Hausenloy & Yellon, 2013)

Translation is challenging because prolonged suppression of neural activity can impair consciousness and function. Neuroprotection must preserve viability without abolishing essential brain operations. Importantly, oxygen tension should be interpreted alongside perfusion, substrate availability, temperature, and metabolic workload.

6. Heart and cardiomyocytes: continuous work under oxygen stress

The myocardium has exceptionally high mitochondrial density and relies predominantly on oxidative metabolism to support continuous contraction. Cardiomyocytes consume oxygen to generate ATP for actomyosin cycling, calcium reuptake by SERCA, ion pumping, and cellular maintenance. Coronary flow is tightly coupled to metabolic demand, and interruption of perfusion rapidly creates ischemia. (Hausenloy & Yellon, 2013)

Unlike some skeletal muscle fibers, cardiomyocytes have limited capacity to sustain contractile work through anaerobic glycolysis alone. During acute ischemia, ATP depletion impairs SERCA and Na+/K+-ATPase, producing cytosolic calcium accumulation, sodium loading, cell swelling, and contractile failure. Anaerobic glycolysis increases but cannot fully meet ATP demand, and lactate-associated acidosis alters enzyme function and ion transport.

Mitochondria become depolarized and may open the mitochondrial permeability transition pore during reperfusion, contributing to cell death. Calcium overload and reactive oxygen species reinforce one another, while endothelial dysfunction and inflammation expand injury beyond the initially ischemic zone. Adaptive responses include rapid reduction of contractility, activation of AMPK, HIF-dependent metabolic changes, and coronary vasodilation. (Hausenloy & Yellon, 2013; Hausenloy & Yellon, 2016)

Ischemic preconditioning describes the phenomenon in which brief, nonlethal ischemic episodes make myocardium more resistant to a subsequent prolonged insult. Signaling mediators include adenosine, bradykinin, nitric oxide, protein kinase C, mitochondrial potassium channels, and prosurvival kinase pathways. These signals can preserve mitochondrial function and reduce permeability transition, although the relative contribution of each pathway varies by species, experimental model, and clinical context. (Hausenloy & Yellon, 2016)

Chronic hypoxia also produces structural remodeling. Capillary density, mitochondrial function, substrate use, and expression of contractile proteins can change. HIF-driven angiogenic signaling may support oxygen delivery, but persistent pulmonary vascular hypoxia increases right ventricular afterload and can cause hypertrophy and eventual failure.

Thus, an adaptive response in one compartment may impose stress elsewhere. Comparative animals provide unusual models. Diving mammals tolerate repeated episodes of bradycardia and peripheral vasoconstriction while maintaining perfusion of the brain and heart. (Ponganis, 2011; Storey, 2007)

Turtles reduce heart rate and cardiac output dramatically during anoxia, matching energy supply to suppressed demand. Naked mole-rats exhibit low resting metabolic rates and unusual tolerance of severe hypoxia; their cardiac and neural adaptations are being investigated for relevance to ischemic injury. These species do not simply possess stronger hearts: they coordinate systemic oxygen delivery, metabolic depression, and cellular protection. (Storey, 2007)

For human cardioprotection, the key lesson is that survival depends on reducing ATP demand, preserving mitochondrial integrity, limiting calcium overload, and controlling reperfusion injury. Any intervention that increases oxygen delivery without controlling downstream redox and calcium disturbances may be insufficient. Conversely, metabolic suppression must be carefully timed because the heart must restore effective pumping when perfusion returns (Fig. 3).

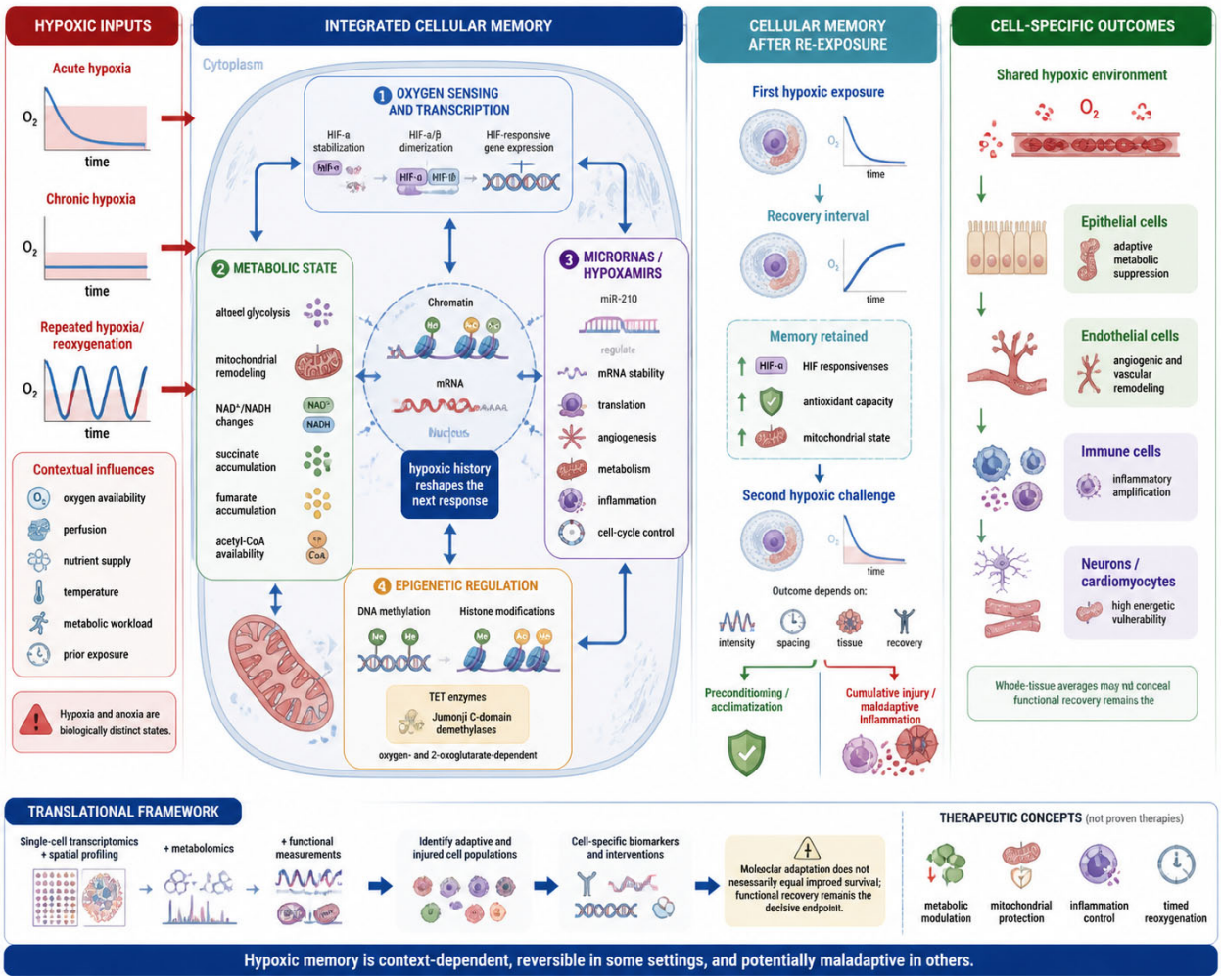


Figure 3. Hypoxia-induced cellular memory through the integration of oxygen sensing, metabolism, microRNAs, and epigenetic regulation.

Hypoxic responses are shaped not only by the immediate oxygen deficit but also by the metabolic and regulatory history of the cell. The left panel illustrates three major hypoxic exposure patterns—acute hypoxia, chronic hypoxia, and repeated hypoxia–reoxygenation—together with contextual influences including oxygen availability, perfusion, nutrient supply, temperature, metabolic workload, and prior exposure. Hypoxia and anoxia are distinguished as biologically different states.

The central panel depicts the integrated cellular-memory network. Oxygen sensing and transcriptional regulation involve hypoxia-inducible factor alpha (HIF-α) stabilization, HIF-α/HIF-1β dimerization, and activation of hypoxia-responsive gene expression. In parallel, hypoxia alters the metabolic state through glycolytic activation, mitochondrial remodeling, changes in the NAD^+/NADH ratio, accumulation of succinate and fumarate, and altered acetyl-CoA availability. These metabolic changes interact with microRNAs or hypoxamirs, including miR-210, which can regulate mRNA stability, translation, angiogenesis, metabolism, inflammation, and cell-cycle progression. Epigenetic regulation provides an additional layer through changes in DNA methylation and histone modifications mediated by oxygen- and 2-oxoglutarate-dependent enzymes, including TET enzymes and Jumonji C-domain histone demethylases. Bidirectional interactions among these pathways allow hypoxic history to reshape subsequent cellular responses.

The re-exposure panel shows a first hypoxic challenge, a recovery interval, and a second hypoxic challenge. Retained changes in HIF responsiveness, antioxidant capacity, and mitochondrial state may support preconditioning or acclimatization; however, excessive intensity, inadequate spacing,

tissue vulnerability, or insufficient recovery may promote cumulative injury and maladaptive inflammation.

The cell-specific outcomes panel emphasizes that a shared hypoxic environment can produce divergent responses among epithelial, endothelial, immune, neuronal, and cardiac cells. Adaptive metabolic suppression, vascular remodeling, inflammatory amplification, and high energetic vulnerability may therefore coexist within the same tissue, and whole-tissue averages may conceal these opposing responses. The translational framework highlights the integration of single-cell transcriptomics, spatial profiling, metabolomics, and functional measurements to identify adaptive and injured cell populations, develop cell-specific biomarkers, and guide exploratory strategies involving metabolic modulation, mitochondrial protection, inflammation control, and timed reoxygenation. These concepts are not presented as established therapies. Molecular adaptation does not necessarily indicate improved survival; functional recovery remains the decisive endpoint. Hypoxic memory is consequently context-dependent, reversible in some settings, and potentially maladaptive in others

7. Kidney: physiological hypoxia and selective vulnerability

The kidney receives a large fraction of cardiac output, yet oxygen distribution within it is highly heterogeneous. The cortex is relatively well oxygenated, while the outer medulla operates at low oxygen tension because of countercurrent vascular architecture and the high ATP demand of sodium reabsorption. Thick ascending limb cells consume substantial ATP to drive Na+/K+-ATPase and coupled transport. (Brezis & Rosen, 1995)

The renal medulla therefore functions near the edge of oxygen supply even under normal conditions. Tubular epithelial cells adapt through glycolytic capacity, altered transport activity, and oxygen-sensing pathways. When oxygen becomes limiting, HIF signaling can induce glucose transporters, glycolytic enzymes, and genes that support cell survival. (Brezis & Rosen, 1995; Lee et al., 2020)

HIF-1α is expressed in several renal cell types, whereas HIF-2α is prominent in interstitial fibroblast-like cells and endothelial populations. Renal interstitial cells are major sources of erythropoietin, linking local oxygen sensing to systemic red-cell production. This is an example of tissue-level sensing influencing whole-body oxygen transport. (Lee et al., 2020)

Acute kidney injury often follows ischemia–reperfusion, sepsis, or nephrotoxic exposure. Proximal tubule cells are vulnerable because of high transport demand and relatively limited glycolytic reserve in some segments. Ischemia disrupts ATP-dependent transport, cytoskeletal organization, cell polarity, and tight junctions. (Brezis & Rosen, 1995)

Reperfusion may generate oxidants and inflammatory signals, while endothelial injury impairs microcirculation. Injured epithelial cells can dedifferentiate, proliferate, and restore the tubular lining, but maladaptive repair may produce fibrosis. HIF activation can be protective by improving metabolic adaptation and supporting vascular responses, yet chronic HIF signaling may contribute to fibrosis or pathological remodeling depending on the cell type and disease stage.

The balance between HIF-1α and HIF-2α is important. Erythropoietin-producing interstitial cells respond to oxygen availability, while endothelial cells regulate perfusion and barrier function. This compartmental organization explains why a single whole-kidney measurement can obscure opposing cell-specific effects.

The kidney also illustrates the importance of oxygen consumption rather than oxygen delivery alone. Reducing tubular sodium transport can lower ATP demand and oxygen consumption, potentially preserving tissue viability. However, excessive reduction in filtration or transport compromises homeostasis. (Brezis & Rosen, 1995)

Comparative anoxia-tolerant animals use much more profound metabolic depression, but humans cannot safely reproduce this state across a complex organ that must continuously regulate fluid,

electrolytes, and acid–base balance. Therapeutic research therefore explores targeted HIF modulation, mitochondrial protection, improved microvascular perfusion, and strategies to reduce tubular energy demand. The challenge is to protect vulnerable segments without disrupting erythropoietin regulation, renal hemodynamics, or normal transport.

Kidney physiology demonstrates that some cells are adapted to chronic low oxygen, while neighboring cells remain susceptible to acute oxygen collapse. Importantly, oxygen tension should be interpreted alongside perfusion, substrate availability, temperature, and metabolic workload.

8. Liver and intestine: oxygen gradients, metabolism, and barrier function

The liver receives dual blood supply from the portal vein and hepatic artery, creating oxygen gradients across the hepatic lobule. Periportal hepatocytes encounter relatively oxygen-rich blood and support oxidative metabolism, gluconeogenesis, and urea synthesis. Pericentral hepatocytes experience lower oxygen and express metabolic programs suited to their local environment, including many cytochrome P450 enzymes. (Kietzmann, 2017)

Zonation is therefore a physiological adaptation to oxygen gradients rather than evidence of tissue failure. Hepatocytes have substantial metabolic flexibility. They can switch among glucose, fatty acids, amino acids, and ketone-related pathways, while HIF signaling modifies glycolysis, lipid metabolism, and stress responses.

During ischemia, ATP depletion impairs membrane transport and bile secretion, while mitochondrial dysfunction promotes oxidative stress. Reperfusion can intensify injury through reactive oxygen species, Kupffer-cell activation, endothelial dysfunction, and inflammatory cytokines. Sinusoidal endothelial cells and stellate cells influence microcirculation, inflammation, and fibrotic repair. (Kietzmann, 2017)

The intestine also contains steep oxygen gradients. Oxygen diffuses from the richly perfused mucosa toward the relatively anaerobic lumen, shaping epithelial metabolism and microbial ecology. Intestinal epithelial cells, particularly colonocytes, use substantial butyrate oxidation when oxygen is available. (Colgan & Taylor, 2010)

HIF signaling in epithelial cells supports barrier integrity by regulating tight junctions, mucins, antimicrobial peptides, and nucleotide metabolism. Physiological hypoxia can therefore reinforce epithelial defense, whereas severe ischemia compromises barrier function and permits microbial products to enter the circulation. Cell-specific HIF actions are important in both organs. (Colgan & Taylor, 2010)

Hepatocyte HIF can alter metabolic and inflammatory programs, while endothelial and immune-cell HIF affects vascular responses and inflammation. In the gut, epithelial HIF may be protective, but chronic hypoxia and inflammation can create conditions that support pathological remodeling or tumor growth. Oxygen gradients also influence stem-cell niches and differentiation, demonstrating that the same pathway can maintain homeostasis or contribute to disease depending on context.

Liver and intestinal adaptation differ from the strategies of anoxia-tolerant vertebrates. These mammalian organs do not generally survive prolonged complete oxygen deprivation by suspending metabolism. Instead, they exploit zonation, substrate flexibility, and coordinated vascular regulation.

Their resilience depends on maintaining microcirculatory flow and rapidly restoring epithelial or hepatocyte integrity after injury. These systems also emphasize interactions between host cells and microbes. The gut microbiota consumes oxygen and produces metabolites that alter epithelial signaling.

Butyrate can support colonocyte energy metabolism and influence histone deacetylases, while microbial products activate innate immune pathways. Hypoxia thus operates within a multicellular ecosystem rather than as an isolated stimulus. Future work should distinguish beneficial

physiological oxygen gradients from pathological ischemia and identify which cell-specific responses preserve barrier and metabolic function. (Colgan & Taylor, 2010).

9. Skeletal muscle: repeated hypoxia and fiber-specific responses

Skeletal muscle experiences transient reductions in oxygen availability during intense contraction because oxygen consumption rises rapidly and intramuscular pressure can restrict perfusion. Unlike the brain, skeletal muscle can tolerate substantial short-lived oxygen fluctuations, partly because it stores phosphocreatine and glycogen and contains fibers with different metabolic profiles. Type I oxidative fibers have high mitochondrial density and capillarity, whereas type II fibers rely more heavily on glycolysis and can generate force rapidly with lower oxidative capacity. (Lundby et al., 2009; Favier et al., 2015)

HIF-1α participates in the muscle response, but its abundance and activity are time dependent. Skeletal muscle may express appreciable HIF-1α under normoxic conditions, and systemic hypoxia does not always produce a large sustained increase. HIF target genes regulate glucose transport, glycolysis, angiogenesis, and pyruvate oxidation. (Favier et al., 2015)

PDK1 can reduce pyruvate entry into mitochondria, while changes in mitochondrial dynamics and mitophagy influence reactive oxygen species. Chronic hypoxia may inhibit fatty-acid oxidation and alter mitochondrial function, but the effects depend on exposure severity, exercise, nutrition, and training status. Muscle adaptation is also governed by AMPK, calcium-dependent signaling, PGC-1α, and mechanotransduction.

AMPK senses energetic stress and can stimulate glucose uptake and mitochondrial quality control. PGC-1α coordinates mitochondrial biogenesis and oxidative phenotype, although hypoxia can alter its regulation. Repeated exercise-induced hypoxia is not identical to sustained environmental hypoxia: contraction supplies calcium signals and mechanical cues, and the muscle receives intermittent reperfusion between bouts. (Favier et al., 2015; Lundby et al., 2009)

Capillary remodeling and myoglobin content influence oxygen diffusion and intracellular storage. VEGF can promote angiogenesis, but human studies of chronic altitude exposure do not consistently show increased muscle capillarity or oxidative enzyme capacity at rest. Severe prolonged hypoxia can reduce muscle mass and performance. (Lundby et al., 2009)

Thus, skeletal muscle is relatively tolerant of episodic oxygen limitation but not immune to chronic oxygen deficit. At the cellular level, myofibers must preserve sarcolemmal integrity, calcium cycling, and ATP supply. Satellite cells contribute to repair, while fibro-adipogenic progenitors and immune cells shape regeneration and fibrosis.

Hypoxia can affect these populations differently, and excessive HIF activity may alter differentiation. Mitochondrial fission and mitophagy remove damaged organelles, while fusion supports metabolic complementation; the balance is important during recovery. Comparisons with turtles and diving mammals show that muscle can be adapted for oxygen conservation and anaerobic work.

Diving mammals redistribute blood flow away from locomotor muscles during dives, reducing peripheral oxygen consumption. Turtles suppress muscle metabolism during anoxia. Humans instead rely on short-term phosphagen stores, glycolysis, and cardiorespiratory acclimatization.

These differences caution against assuming that mechanisms in naturally tolerant species operate identically in human muscle. Importantly, oxygen tension should be interpreted alongside perfusion, substrate availability, temperature, and metabolic workload. This comparative framework supports careful interpretation.

10. Placenta and development: hypoxia as a normal signal

Early embryonic development occurs at oxygen tensions lower than those encountered in many adult tissues. The placenta develops within a dynamic oxygen environment, and oxygen availability influences trophoblast differentiation, vascular development, nutrient transport, and

mitochondrial function. Physiological hypoxia is therefore a developmental signal. (Burton et al., 2021; Jiang et al., 2021)

Excessively high oxygen exposure during early gestation can also be harmful, illustrating that normal development requires regulated oxygen rather than maximal oxygenation. Trophoblast populations respond to oxygen through HIF signaling. HIF-1α and HIF-2α regulate transcriptional programs involved in glycolysis, angiogenic signaling, invasion, and differentiation. (Burton et al., 2021)

As placental perfusion develops, oxygen exposure changes and trophoblast cells remodel their metabolism. Placental mitochondria are not merely ATP generators; they participate in redox signaling, steroid metabolism, apoptosis, and adaptation to fluctuating substrate and oxygen availability. At high altitude, maternal hypobaric hypoxia challenges placental oxygen delivery.

Yet outcomes differ across populations and individuals. Placental adaptation may involve reduced oxygen consumption, altered mitochondrial respiration, vascular remodeling, and changes in nutrient transport. Reduced placental oxygen use can help preserve fetal oxygen availability, but it may come at the cost of lower energy-dependent transport and fetal growth. (Tissot van Patot et al., 2010; Ahrens & Singer, 2025)

High-altitude pregnancy is therefore a balance between conserving oxygen and sustaining nutrient delivery. The maternal vascular system and placenta interact. Endothelial function, nitric oxide signaling, uterine blood flow, and angiogenic factors influence perfusion.

Excessive HIF activation or abnormal angiogenic balance may contribute to preeclampsia and fetal growth restriction, although the mechanisms are multifactorial. Some highland populations show relative protection from adverse pregnancy outcomes, associated with long-term genetic and physiological adaptation. Tibetan and Andean populations do not use identical strategies, and population-specific findings should not be generalized to all high-altitude pregnancies (Ahrens & Singer, 2025; Getu et al., 2026)

Developmental hypoxia also shapes stem-cell behavior. Low oxygen can preserve an undifferentiated state, alter epigenetic enzymes, and influence cell-cycle progression. Oxygen-sensitive dioxygenases use oxygen and 2-oxoglutarate, so hypoxia can change DNA and histone modification indirectly through altered enzyme activity (Jiang et al., 2021).

These effects link oxygen sensing to developmental gene regulation beyond HIF. The placenta differs from adult kidney or muscle because oxygen gradients are integrated with maternal-fetal exchange and developmental timing. The key adaptive outcome is not simply cell survival but coordinated growth of two organisms.

Comparative studies in high-altitude mammals and human populations can clarify how oxygen sensing, mitochondrial metabolism, and vascular architecture interact. Clinical interpretation must distinguish normal developmental hypoxia from placental insufficiency, which involves inadequate perfusion and nutrient exchange. Importantly, oxygen tension should be interpreted alongside perfusion, substrate availability, temperature, and metabolic workload.

11. Vascular endothelium, blood, and systemic oxygen delivery

Endothelial cells form the interface between blood and tissues and actively regulate oxygen delivery. They sense shear stress, oxygen tension, metabolites, inflammatory mediators, and growth factors. HIF signaling can induce VEGF and other angiogenic mediators, while nitric oxide synthase regulates vascular tone. (Semenza, 2012; Lee et al., 2020)

Nitric oxide activates soluble guanylate cyclase in smooth muscle, increasing cyclic GMP and promoting relaxation. During hypoxia, nitric oxide bioavailability can change through altered synthesis, scavenging, and nitrite reduction. Angiogenesis is a major response to sustained tissue hypoxia.

Endothelial cells proliferate, migrate, and form new vessels under VEGF and other signals. Not all new vessels are functionally effective: pathological angiogenesis can be leaky, disorganized, or

poorly perfused. Pericytes and smooth-muscle cells stabilize vessels, while extracellular matrix remodeling determines vessel maturation. (Jiang et al., 2021)

HIF-regulated angiogenesis is therefore a coordinated tissue process rather than a single-gene effect. Blood provides a second level of adaptation. Renal HIF-2α stimulates erythropoietin production, which promotes survival and differentiation of erythroid progenitors in bone marrow. Red-cell mass and hemoglobin concentration can increase during chronic hypoxia, raising arterial oxygen content. However, excessive erythrocytosis increases blood viscosity and may impair microvascular flow. Iron availability, hepcidin, transferrin, and erythroferrone regulate the capacity to produce hemoglobin. (Petousi & Robbins, 2014; Getu et al., 2026)

The adaptive benefit of increased red-cell mass depends on the balance between oxygen content and viscosity. High-altitude human populations show divergent solutions. Many Andean highlanders exhibit higher hemoglobin concentrations, whereas Tibetans often maintain comparatively lower hemoglobin and higher ventilation or blood flow. (Petousi & Robbins, 2014; Getu et al., 2026)

Genetic variation in EPAS1 and EGLN1, central components of the HIF pathway, contributes to Tibetan adaptation. Ethiopian highlanders show yet other patterns. These differences demonstrate that natural selection can tune oxygen delivery at several points in the cascade rather than maximizing one variable. (Lorenzo et al., 2014; Petousi & Robbins, 2014)

Nitric oxide and nitrite also feature in hypoxia-tolerant animals. Under low oxygen, nitrite can be reduced to nitric oxide by deoxyhemoglobin, myoglobin, and other proteins, potentially supporting vasodilation and cellular signaling. Diving mammals redistribute blood flow through bradycardia and peripheral vasoconstriction while preserving central organs. (Ponganis, 2011)

Turtles use metabolic depression and vascular adjustments during anoxia. These systemic strategies complement cell-autonomous mechanisms. The endothelium can also be injured by ischemia–reperfusion, inflammation, and oxidative stress.

Barrier leakage, leukocyte adhesion, and microvascular obstruction may persist even after large-vessel flow is restored. Effective adaptation must therefore preserve microvascular function, red-cell deformability, and tissue-level distribution of oxygen, not merely arterial oxygen saturation. Importantly, oxygen tension should be interpreted alongside perfusion, substrate availability, temperature, and metabolic workload.

12. Turtles and crucian carp: metabolic depression and anoxia tolerance

Freshwater turtles such as painted turtles and red-eared sliders can survive prolonged winter anoxia in cold water. Crucian carp also tolerate extended periods without oxygen. Their survival is not based on maintaining normal aerobic activity without oxygen. (Storey, 2007; Warren & Jackson, 2008)

Instead, they reduce metabolic rate dramatically, suppressing ATP demand until anaerobic pathways and stored fuels can support essential functions. Low temperature further reduces reaction rates and energy requirements, making prolonged survival possible. In turtles, the brain, heart, and skeletal muscle undergo coordinated metabolic depression. (Storey, 2007)

Protein synthesis, cell-cycle progression, and other energy-intensive processes are suppressed. Ion-channel activity and neurotransmission are reduced, conserving ATP needed to maintain membrane gradients. Adenosine signaling, inhibitory neurotransmission, and changes in gene expression contribute to neural quiescence.

These responses delay anoxic depolarization and preserve cellular integrity. Anaerobic glycolysis provides ATP, but it produces lactate. Turtles manage this burden through buffering and, in some species, sequestration of lactate as calcium lactate in the shell and skeleton. (Storey, 2007; Warren & Jackson, 2008)

The shell is therefore not merely a protective structure; it participates in acid–base management during prolonged anoxia. The capacity to tolerate lactate accumulation is a major difference from

mammals, in which severe lactic acidosis rapidly compromises function. Molecular regulation includes stress-response transcription factors, FoxO, heat-shock proteins, NF-κB, p53-related pathways, and chromatin modifiers. (Jackson, 2004; Warren & Jackson, 2008)

The exact contribution of individual regulators varies by tissue and experimental condition. Suppression of transcription and translation reduces ATP use, while chaperones and antioxidant systems protect macromolecules. Nitric oxide and nitrite signaling may coordinate vascular and metabolic responses.

Reoxygenation after anoxia requires restoration of normal metabolism without overwhelming antioxidant defenses. Crucian carp use a different but complementary strategy. During winter anoxia, they convert lactate to ethanol through a modified pyruvate decarboxylation pathway and release ethanol across the gills.

This avoids the extreme accumulation of lactate that would otherwise cause fatal acidosis. The pathway involves duplicated enzymes and specialized regulation that evolved in cyprinid fishes. It illustrates how evolutionary innovation can solve a metabolic waste problem rather than simply increase ATP production. (Fagernes et al., 2017)

These vertebrates provide powerful models for ischemia research because they reveal that cellular survival can be achieved by lowering demand, stabilizing ion gradients, managing acid load, and limiting oxidative injury. However, their strategies are inseparable from cold tolerance, ecological history, and whole-organism physiology. Human organs cannot simply adopt turtle-like anoxia tolerance without coordinated systemic changes.

13. Naked mole-rats: mammalian hypoxia and anoxia adaptations

The naked mole-rat, Heterocephalus glaber, lives in crowded subterranean colonies where oxygen can become extremely low and carbon dioxide high. It is unusually tolerant of hypoxia for a mammal. Reported adaptations include low resting metabolic rate, high-affinity hemoglobin, suppression of physiological activity, intrinsic neural tolerance, and the ability to use fructose-supported anaerobic glycolysis during anoxia. (Amoroso et al., 2023)

These traits form an integrated response to a chronic ecological challenge. A landmark study demonstrated that naked mole-rats can survive a period of complete oxygen deprivation by switching to fructose metabolism. Their tissues express the fructose transporter GLUT5 and the enzyme ketohexokinase. (Park et al., 2017; Amoroso et al., 2023)

Fructose enters glycolysis downstream of phosphofructokinase, a major regulatory step that can inhibit glycolytic flux when ATP and citrate accumulate. This pathway allows continued substrate-level ATP production under conditions in which conventional glucose glycolysis is constrained. Lactate is produced, but the animal's systemic response and low energy demand help maintain viability. (Park et al., 2017)

The brain is a particularly informative tissue. Naked mole-rat neurons maintain synaptic transmission longer than mouse neurons during hypoxia and can recover after prolonged anoxia in experimental preparations. Reduced neuronal activity and altered ion-channel regulation conserve ATP. (Larson & Park, 2009; Larson et al., 2014)

MicroRNA responses also modify translation, proliferation, inflammation, and metabolic pathways. Hypoxia and anoxia do not necessarily evoke identical programs: fructose utilization is especially associated with anoxia, whereas severe hypoxia can involve different glycolytic and regulatory patterns. Cardiovascular adaptations include low heart rate and reduced activity during severe oxygen limitation, limiting whole-body oxygen consumption. (Chan & Loscalzo, 2010; Nallamshetty et al., 2013)

High-affinity hemoglobin can support oxygen loading at low partial pressure, although oxygen unloading to tissues must also remain effective. The animal's tolerance of carbon dioxide is linked to altered sensory responses to acidosis, demonstrating that hypoxia adaptation is embedded within acid–base physiology. Naked mole-rats are not uniformly protected in every context.

Responses can vary with tissue, developmental stage, social caste, and reproductive status. Recent experimental work found that acute hypoxia altered glycolytic and glucose-regulatory responses differently in subordinate animals and queens. These findings caution against describing the species as having a single fixed metabolic switch and should not be conflated with the distinct fructose-supported pathway reported during anoxia. (Ojaghi & Pamenter, 2025)

The translational value is conceptual rather than immediate. Human neurons and cardiomyocytes do not normally express the same fructose-utilization program at comparable levels. Nevertheless, the study suggests possible avenues: bypassing rate-limiting glycolytic control, reducing energy demand, stabilizing ion homeostasis, and coordinating systemic responses. (Park et al., 2017)

Any therapeutic manipulation must avoid severe acidosis, hypoglycemia, and loss of essential organ function. Importantly, oxygen tension should be interpreted alongside perfusion, substrate availability, temperature, and metabolic workload. Measurements from whole tissue can conceal opposing responses among epithelial, stromal, immune, and vascular populations (Fig. 4).

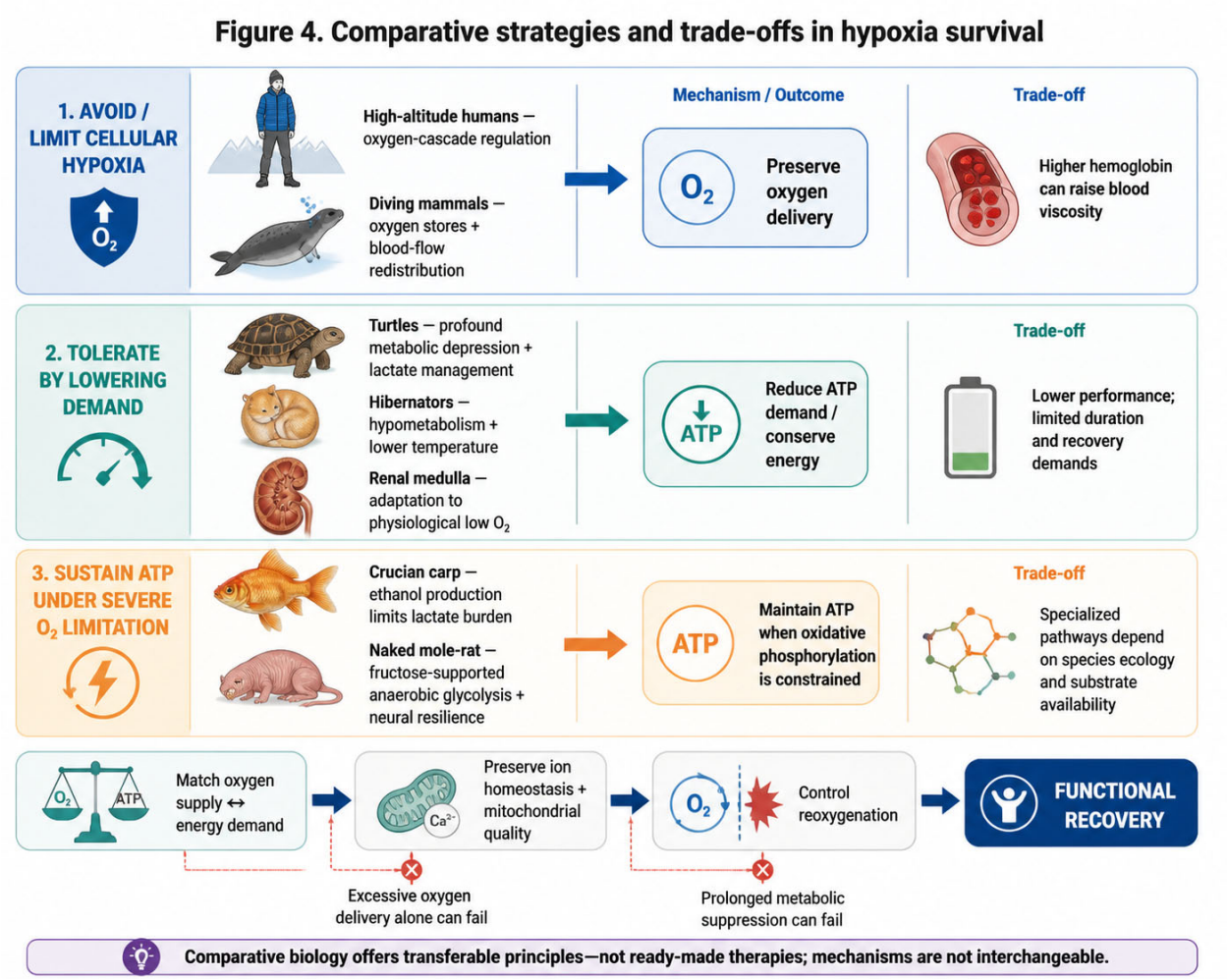


Figure 4. Comparative strategies and trade-offs in hypoxia survival. Across humans and other organisms, survival under oxygen limitation involves three partially overlapping strategies: limiting cellular hypoxia through increased oxygen acquisition or redistribution, as illustrated by high-altitude adaptation and oxygen storage and blood-flow redistribution in diving mammals; tolerating low oxygen by reducing energy demand, as in the metabolic depression of turtles and hibernators and the adaptation of renal medullary cells to physiological hypoxia; and sustaining ATP production under severe oxygen limitation through specialized anaerobic pathways, including ethanol production in crucian carp and fructose-supported glycolysis in naked mole-rats (Petousi & Robbins, 2014; Brezis & Rosen, 1995; Kooyman & Ponganis, 1998; Storey, 2007; Fagernes et al., 2017; Park et al., 2017). These strategies entail context-dependent trade-offs, including increased blood viscosity, reduced performance, and dependence on species-specific physiology and substrate availability. Despite their mechanistic diversity, they converge on the need to match oxygen supply with energy demand, preserve ion homeostasis and mitochondrial quality, and control reoxygenation to achieve functional recovery. Comparative adaptations therefore provide transferable physiological principles rather than directly interchangeable therapeutic solutions.

14. Diving mammals and hibernators: oxygen management at the organismal scale

Seals, whales, and other diving mammals experience repeated cycles of apnea, hypoxemia, and reoxygenation. Their survival depends on oxygen stores, cardiovascular control, and selective perfusion. Large blood volumes, elevated hemoglobin, and high muscle myoglobin concentrations increase oxygen storage. (Kooyman & Ponganis, 1998; Ponganis, 2011)

During dives, vagally mediated bradycardia reduces cardiac work, while peripheral vasoconstriction redistributes blood toward the brain and heart. Locomotor muscle perfusion can fall markedly, limiting oxygen consumption in less immediately essential tissues. Myoglobin binds oxygen within muscle and can facilitate intracellular oxygen transport as well as serve as an oxygen reserve. (Ponganis, 2011)

Diving mammals often have high myoglobin concentrations and structural adaptations that support its solubility. Hemoglobin properties also influence oxygen loading and unloading. The dive response is therefore a systems-level strategy that complements cellular tolerance: oxygen is conserved and allocated to organs with high priority. (Kooyman & Ponganis, 1998; Ponganis, 2011)

Repeated ischemia and reperfusion would be damaging in many mammals, yet diving species show adaptations in antioxidant defenses, nitric oxide signaling, and inflammatory regulation. Nitrite may serve as a reservoir for nitric oxide under hypoxic conditions, influencing vascular tone and mitochondrial function. However, the precise contribution of nitrite and other pathways differs among species and remains an active research area.

Hibernating mammals, including arctic ground squirrels, undergo profound reductions in body temperature, heart rate, ventilation, and metabolic rate. Cooling reduces ATP demand and slows biochemical reactions. During torpor, blood flow and oxygen consumption are greatly reduced, but essential cellular functions are maintained. (Williams & Ponganis, 2021)

Periodic arousals restore normal temperature and metabolism. These transitions create repeated oxidative challenges, and hibernators display adaptations that limit oxidative damage and inflammation. Brain protection in hibernators includes altered neurotransmission, ion-channel regulation, and preservation of synaptic structures during torpor. (Williams & Ponganis, 2021)

Some changes are reversible, allowing rapid return to normal neural function during arousal. This reversibility distinguishes physiological metabolic depression from pathological injury. Cells are not simply damaged and repaired; they enter a regulated low-energy state.

Human clinical care sometimes uses controlled temperature reduction to lower metabolic demand, but the magnitude and coordination achievable in hibernators are not currently reproducible in humans. Cooling can cause arrhythmias, coagulopathy, infection risk, and other complications. Likewise, inducing peripheral vasoconstriction or bradycardia without precise control could compromise organ perfusion.

The comparison emphasizes that successful oxygen management is hierarchical. Blood oxygen stores, circulation, tissue priorities, mitochondrial metabolism, and cell signaling must be coordinated. A cell-autonomous therapy may fail if systemic delivery remains inadequate, while improved oxygen delivery may not prevent injury if cells cannot manage calcium, redox balance, and reoxygenation.

15. Cell death, autophagy, and repair under oxygen limitation

When adaptive mechanisms fail, hypoxia can trigger cell death through apoptosis, necrosis, necroptosis, ferroptosis, and other regulated pathways. The dominant outcome depends on severity, duration, cell type, and inflammatory environment. Severe ATP depletion impairs membrane pumps and causes swelling and membrane rupture, producing necrotic injury. (Lee et al., 2020; Zhou et al., 2022)

More moderate stress may activate apoptosis through mitochondrial cytochrome c release, caspases, and pro- and anti-apoptotic BCL-2 family proteins. Autophagy recycles damaged organelles and macromolecules, providing substrates and removing potentially harmful structures. During hypoxia, AMPK activation and mTORC1 inhibition can promote autophagy. (Lee et al., 2020)

Selective mitophagy removes dysfunctional mitochondria, limiting reactive oxygen species and preserving mitochondrial quality. Yet autophagy is context dependent: insufficient clearance allows damaged organelles to accumulate, whereas excessive self-digestion can contribute to cell loss. The timing and extent of autophagy are therefore critical. (Lee et al., 2020)

Ferroptosis is an iron-dependent form of regulated cell death driven by phospholipid peroxidation. It is influenced by iron availability, glutathione, glutathione peroxidase 4, and lipid composition. Hypoxia can alter iron metabolism and redox pathways, potentially changing ferroptosis susceptibility. (Zhou et al., 2022)

During reperfusion, iron release and oxidant generation may amplify lipid damage. Ferritin storage, iron export, and antioxidant systems can influence whether cells cross this threshold. The unfolded protein response is activated when endoplasmic reticulum stress disrupts protein folding. (Zhou et al., 2022)

PERK signaling can reduce global translation through eIF2α phosphorylation while selectively increasing stress-response proteins such as ATF4. IRE1 and ATF6 activate additional adaptive programs. Initially, these pathways restore proteostasis, but prolonged unresolved stress can promote apoptosis. (Lee et al., 2020)

Oxygen limitation can affect disulfide bond formation and ATP-dependent protein folding, linking hypoxia to endoplasmic reticulum stress. Repair requires coordinated actions by surviving parenchymal cells, stem or progenitor cells, endothelial cells, fibroblasts, and immune cells. Macrophages can adopt inflammatory or reparative states, although the binary M1/M2 classification is an oversimplification.

Angiogenesis restores perfusion, while extracellular matrix remodeling supports tissue architecture. Excessive or persistent repair signaling can lead to fibrosis. Hypoxia-tolerant animals often avoid activating catastrophic injury pathways by suppressing metabolism and stabilizing cellular homeostasis.

In humans, the goal is often to prevent irreversible cell death during a finite ischemic interval and then support orderly repair. Therapeutic manipulation of autophagy, ferroptosis, or unfolded-protein signaling is promising but challenging because these pathways are essential in normal physiology and have different roles across tissues. Importantly, oxygen tension should be interpreted alongside perfusion, substrate availability, temperature, and metabolic workload.

16. Reoxygenation injury: the second half of the problem

Restoring oxygen is essential after ischemia, but reoxygenation can itself damage cells. During oxygen deprivation, electron carriers become highly reduced, mitochondrial membrane potential may collapse, calcium accumulates, and antioxidant systems can become depleted. When oxygen returns, electron flow resumes in a disturbed metabolic environment, generating reactive oxygen species. (Hausenloy & Yellon, 2013; Hausenloy & Yellon, 2016)

These oxidants damage mitochondrial DNA, proteins, membrane lipids, and signaling complexes. The severity of reperfusion injury depends on the duration of ischemia and the metabolic state at the moment of oxygen restoration. Mitochondrial permeability transition is a central event in many models of reperfusion injury. (Hausenloy & Yellon, 2013)

High matrix calcium, oxidative stress, and phosphate can promote opening of a high-conductance permeability pathway, causing loss of membrane potential, ATP synthesis failure, swelling, and potentially cell death. The exact molecular composition and regulation of the permeability transition pore remain debated, but its functional importance in ischemia–reperfusion is well established. Calcium handling is another critical determinant. (Hausenloy & Yellon, 2013)

Ischemia impairs ATP-dependent calcium extrusion and sequestration. During reperfusion, rapid restoration of pH and ion gradients can activate sodium–hydrogen exchange, increase intracellular sodium, and drive reverse-mode sodium–calcium exchange. This can worsen calcium overload. (Hausenloy & Yellon, 2013)

Cardiomyocytes are especially vulnerable because calcium cycling is central to contraction, while neurons are vulnerable because glutamate receptor activation and depolarization increase calcium entry. Endothelial cells and immune cells contribute to reperfusion injury. Endothelial swelling, reduced nitric oxide bioavailability, leukocyte adhesion, platelet activation, and microvascular obstruction can prevent uniform tissue reperfusion. (Hausenloy & Yellon, 2013)

Neutrophils and macrophages release oxidants, proteases, and cytokines. Complement activation and damage-associated molecular patterns amplify inflammation. Thus, successful restoration of large-vessel flow does not guarantee restoration of microvascular oxygen delivery. (Hausenloy & Yellon, 2013)

Natural hypoxia-tolerant species provide models of controlled transitions. Hibernators repeatedly rewarm from torpor without the same degree of oxidative damage seen in nonhibernators. Diving mammals experience repeated oxygen fluctuations, while turtles reoxygenate after prolonged anoxia. (Williams & Ponganis, 2021; Storey, 2007)

Their antioxidant capacity, mitochondrial regulation, and inflammatory control may contribute to protection. These adaptations are not fully understood and may differ among species. Clinical strategies include rapid reperfusion when indicated, limiting ischemic duration, controlling temperature and metabolic demand in selected contexts, and investigating agents that stabilize mitochondria or modulate inflammation.

However, delaying reperfusion to avoid oxidants is generally not appropriate in acute ischemic disease. The challenge is to restore oxygen while minimizing downstream injury. Hypoxia tolerance should therefore be defined by both survival during oxygen deprivation and functional recovery after reoxygenation.

17. MicroRNAs, epigenetics, and cellular memory of hypoxia

The hypoxic response extends beyond transcription factors to post-transcriptional and epigenetic regulation. MicroRNAs are short noncoding RNAs that bind target messenger RNAs and alter their stability or translation. Hypoxia-regulated microRNAs, sometimes termed hypoxamirs or oxymiRs, can influence angiogenesis, metabolism, apoptosis, inflammation, and cell-cycle progression. (Chan & Loscalzo, 2010; Chan et al., 2012; Nallamshetty et al., 2013)

miR-210 is a well-studied HIF-responsive microRNA that can regulate mitochondrial metabolism and iron–sulfur cluster assembly. Other microRNAs may alter endothelial behavior, neuronal activity, or metabolic enzyme abundance. In naked mole-rat brain, hypoxia-responsive microRNAs have been associated with suppression of energy-expensive translation and proliferation, alongside changes in neuroprotective and inflammatory pathways. (Chan et al., 2012; Nallamshetty et al., 2013)

Importantly, the molecular profile during hypoxia differs from that during anoxia, and the use of fructose is not necessarily the dominant fuel in every oxygen-deprivation condition. These observations illustrate how post-transcriptional regulation can fine-tune metabolism beyond the canonical HIF response. Epigenetic enzymes are also oxygen sensitive.

Ten-eleven translocation enzymes that modify DNA and Jumonji C-domain histone demethylases require oxygen and 2-oxoglutarate. Reduced oxygen can alter their catalytic activity, potentially changing DNA methylation and histone marks. Histone acetylation is influenced by acetyl-CoA availability and histone deacetylase activity. (Jiang et al., 2021; Lee et al., 2020)

These changes can modify chromatin accessibility and the persistence of hypoxia-responsive gene expression. Metabolic intermediates connect mitochondrial function to epigenetics. Succinate and fumarate can accumulate when tricarboxylic acid cycle flux is altered and inhibit 2-oxoglutarate-dependent dioxygenases. (Lee et al., 2020)

Changes in NAD+/NADH can affect sirtuin activity, while acetyl-CoA availability influences histone acetylation. Thus, hypoxia can alter gene regulation through both oxygen sensing and shifts in cellular metabolism. Repeated hypoxic exposure may create a form of cellular memory.

Prior exposure can alter HIF responsiveness, antioxidant defenses, mitochondrial function, and inflammatory signaling during subsequent challenges. This phenomenon is often described as preconditioning or acclimatization, but it is not universally protective. Repeated exposure can also cause cumulative injury, vascular remodeling, or maladaptive inflammation. (Hausenloy & Yellon, 2016)

The effect depends on intensity, spacing, tissue, and recovery. These regulatory layers may explain why identical oxygen tensions produce different responses in different cells. Chromatin state, microRNA abundance, metabolic history, and differentiation state shape the available response.

Future studies combining single-cell transcriptomics, spatial profiling, metabolomics, and functional measurements will help identify which cell populations adapt and which are injured within the same tissue. Importantly, oxygen tension should be interpreted alongside perfusion, substrate availability, temperature, and metabolic workload. Measurements from whole tissue can conceal opposing responses among epithelial, stromal, immune, and vascular populations.

18. Comparative synthesis: shared modules and evolutionary solutions

Across humans and other organisms, several recurring modules support survival under oxygen limitation. First, oxygen sensing changes gene expression through HIF and associated pathways. Second, energy demand is reduced through suppression of translation, proliferation, contractility, or neuronal activity. (Lee et al., 2020; Semenza, 2012)

Third, metabolism shifts toward pathways that require less oxygen or can produce ATP without oxidative phosphorylation. Fourth, redox defenses and organelle quality control limit damage. Fifth, vascular and systemic responses redistribute oxygen toward essential tissues.

The relative importance of each module differs. Human skeletal muscle can tolerate repeated transient hypoxia partly because it has phosphocreatine stores, glycolytic fibers, and adaptive signaling. The renal medulla is chronically exposed to low oxygen and is specialized for local metabolic conditions. (Favier et al., 2015; Brezis & Rosen, 1995)

Neurons and cardiomyocytes are vulnerable because their ATP demands and electrical or contractile functions cannot be suppressed indefinitely without loss of function. The placenta uses oxygen gradients as developmental cues, while endothelial cells coordinate oxygen distribution. Turtles demonstrate extreme metabolic depression and management of lactate burden. (Larson et al., 2014; Burton et al., 2021)

Crucian carp evolved ethanol production to avoid lethal lactate accumulation. Diving mammals store oxygen and redistribute blood flow. Hibernators combine hypometabolism with temperature reduction and protection during arousal. (Fagernes et al., 2017; Kooyman & Ponganis, 1998; Storey, 2007)

Naked mole-rats add mammalian adaptations including fructose-based anaerobic glycolysis and unusual neural tolerance. These strategies are not interchangeable; each solves a distinct ecological problem. A key distinction is between tolerance and avoidance. (Park et al., 2017; Amoroso et al., 2023)

Some organisms avoid cellular hypoxia by increasing oxygen stores, ventilation, or perfusion. Others tolerate low oxygen by reducing demand. Still others maintain ATP production through unusual anaerobic pathways.

In practice, successful species combine several approaches. Human high-altitude populations primarily alter the oxygen cascade and its regulation, while naturally anoxia-tolerant species can profoundly suppress cellular demand. The evolutionary comparison also reveals trade-offs. (Petousi & Robbins, 2014; Getu et al., 2026)

Increased hemoglobin raises oxygen content but can increase viscosity. Angiogenesis improves supply but may produce fragile vessels. Glycolysis supports ATP generation but yields less energy and can acidify tissues.

Mitochondrial suppression limits oxygen use but may impair recovery if prolonged. Metabolic depression conserves energy but reduces performance and responsiveness. No adaptation is cost-free.

The most transferable principles are therefore systems-level: match demand to supply, preserve membrane gradients, maintain mitochondrial quality, control reoxygenation, and tailor responses to cell identity. It is unlikely that a single molecular target will reproduce the resilience of a naturally tolerant animal. Instead, future therapies may need combinations of transient metabolic modulation, vascular support, and cell-specific protection.

19. Human disease and therapeutic implications

Hypoxia contributes to myocardial infarction, ischemic stroke, acute kidney injury, peripheral arterial disease, chronic lung disease, anemia, high-altitude illness, and solid tumor biology. In each condition, oxygen deprivation interacts with inflammation, nutrient supply, vascular structure, and tissue demand. A therapy that is beneficial in one disease may be harmful in another because HIF, angiogenesis, glycolysis, and cell death pathways have context-dependent effects. (Lee et al., 2020; Hausenloy & Yellon, 2013)

HIF prolyl hydroxylase inhibitors are used or investigated to stimulate endogenous erythropoietin and improve anemia in selected settings. Their effects extend beyond erythropoiesis because HIF regulates iron metabolism, angiogenesis, and glycolysis. The therapeutic window depends on disease context and safety monitoring. (Lee et al., 2020)

Chronic activation of HIF could be undesirable in malignancy or pathological vascular remodeling. Conversely, local or transient HIF activation may support tissue repair in some ischemic settings. Metabolic interventions aim to reduce oxygen demand or improve ATP generation.

Potential strategies include modulating mitochondrial substrate use, AMPK, mTOR, pyruvate dehydrogenase, and autophagy. However, inhibiting oxidative metabolism can impair organ function if glycolytic capacity is insufficient. Fructose-supported glycolysis in naked mole-rats is a compelling evolutionary discovery, but introducing this pathway into human tissues would require rigorous evaluation of enzyme expression, substrate availability, acid–base consequences, and systemic metabolic effects.

Neuroprotective approaches inspired by tolerant species include reducing excitotoxicity, stabilizing ion channels, supporting astrocyte-neuron metabolic exchange, and controlling inflammation. Cardioprotection focuses on limiting calcium overload, preserving mitochondrial function, and reducing reperfusion injury. Kidney protection may involve reducing tubular oxygen consumption, preserving microvascular flow, and promoting adaptive epithelial repair. (Larson et al., 2014; Hausenloy & Yellon, 2013; Brezis & Rosen, 1995)

Placental research aims to distinguish physiological hypoxia from impaired perfusion and to understand population-specific high-altitude adaptation. The timing of intervention is crucial. Acute ischemia, chronic hypoxia, preconditioning, and reoxygenation represent distinct phases. (Burton et al., 2021; Ahrens & Singer, 2025)

A treatment that suppresses metabolism during ischemia may be beneficial briefly but harmful if continued during recovery. Similarly, antioxidant therapy may be ineffective if administered too late or may interfere with physiological redox signaling. Cell-specific delivery and biomarkers of tissue oxygenation could improve precision.

Translation from animal models requires attention to body temperature, metabolic rate, life history, and species-specific pathways. Turtles and hibernators are ectothermic or seasonally hypometabolic; naked mole-rats have evolved specialized metabolism; diving mammals possess unusual oxygen stores. Human clinical trials must test whether a mechanism is both feasible and safe in the relevant organ. (Storey, 2007; Park et al., 2017; Ponganis, 2011)

Comparative biology offers principles and targets, not ready-made treatments. Importantly, oxygen tension should be interpreted alongside perfusion, substrate availability, temperature, and metabolic workload. Measurements from whole tissue can conceal opposing responses among epithelial, stromal, immune, and vascular populations.

20. Conclusions

Survival during hypoxia is a coordinated property of cells, tissues, and whole organisms. Mammalian oxygen sensing through PHD–VHL–HIF signaling provides a conserved molecular framework, but its consequences depend on cell identity, metabolic state, oxygen history, and systemic physiology. HIF regulates glycolysis, angiogenesis, erythropoiesis, and survival, while AMPK, mTOR, mitochondrial remodeling, autophagy, redox systems, and epigenetic regulation shape the final response. (Kaelin & Ratcliffe, 2008; Lee et al., 2020; Semenza, 2012)

Human tissues illustrate diverse strategies. Neurons and cardiomyocytes are vulnerable because they require continuous ATP to sustain electrical and contractile function. Renal medullary cells are adapted to physiological low oxygen but remain susceptible to severe ischemia. (Larson et al., 2014; Brezis & Rosen, 1995)

Liver and intestine use zonation and barrier-associated responses, skeletal muscle tolerates repeated transient hypoxia, and placenta uses oxygen gradients as developmental signals. Endothelial and blood-cell responses coordinate oxygen delivery across the organism. Naturally tolerant animals reveal additional solutions. (Kietzmann, 2017; Colgan & Taylor, 2010; Favier et al., 2015; Burton et al., 2021)

Turtles and crucian carp survive prolonged anoxia through metabolic depression and specialized management of anaerobic end products. Diving mammals conserve oxygen through storage and redistribution. Hibernators suppress metabolism and protect tissues during torpor and arousal. (Fagernes et al., 2017; Storey, 2007; Ponganis, 2011)

Naked mole-rats combine low metabolic demand, unusual neural resilience, and fructose-supported glycolysis during anoxia. These mechanisms demonstrate that oxygen dependence can be modified by evolution, but they are inseparable from each species' ecology and physiology. The comparison yields a unifying principle: cells survive when energy demand, ATP production, ion homeostasis, redox balance, and tissue oxygen supply remain matched. (Park et al., 2017; Amoroso et al., 2023)

Increasing oxygen delivery alone may not prevent injury if mitochondrial and calcium disturbances are uncontrolled. Conversely, reducing metabolism without preserving essential function may be harmful. Reoxygenation must be considered part of the hypoxic insult because it can initiate oxidant production, inflammation, and mitochondrial injury. (Hausenloy & Yellon, 2013; Zhou et al., 2022)

For human medicine, the most useful lessons are likely to be modular rather than wholesale imitation of tolerant species. Carefully timed metabolic suppression, mitochondrial quality control, improved microvascular perfusion, and cell-specific signaling modulation may improve outcomes in ischemia and chronic hypoxic disease. Translation requires direct testing in human-relevant systems and clinical trials.

The field's central challenge is to convert comparative biological insight into interventions that protect tissue while preserving normal function. Importantly, oxygen tension should be interpreted alongside perfusion, substrate availability, temperature, and metabolic workload. Measurements from whole tissue can conceal opposing responses among epithelial, stromal, immune, and vascular populations.

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Culturology

IMPLEMENTING EUROPEAN PRACTICES OF CULTURAL HERITAGE MANAGEMENT IN KAZAKHSTAN'S MUSEUMS AND UNESCO WORLD HERITAGE PROPERTIES

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Abstract. The article examines how European practices of cultural heritage management can be adapted in Kazakhstan. It compares the approaches of France, Italy and Germany to the management of UNESCO World Heritage properties and museums. The article focuses on management plans, the assessment of management effectiveness with the Enhancing Our Heritage Toolkit 2.0, participatory management, public-private partnership and digitalization. With reference to the Mausoleum of Khoja Ahmed Yasawi, the Petroglyphs of Tamgaly and the Rock Mosques of Mangystau, the article formulates recommendations for modernizing the institutional system of heritage protection and use in Kazakhstan.

Keywords. Cultural heritage, museum management, UNESCO World Heritage properties, European experience, management plan, Kazakhstan, participatory management, heritage digitalization.

Introduction

For Kazakhstan, cultural heritage is a basis of national identity and a resource for the development of its regions [13]. The country accepted the Convention concerning the Protection of the World Cultural and Natural Heritage in 1994. Seven properties on its territory are now inscribed on the World Heritage List [12]. The four cultural properties are the Mausoleum of Khoja Ahmed Yasawi (2003), the Petroglyphs within the Archaeological Landscape of Tamgaly (2004), the Chang'an-Tianshan Corridor of the Silk Roads (2014, jointly with China and Kyrgyzstan) and the Rock Mosques and Associated Sacred Sites of Mangystau, inscribed in 2026 [11]. The three natural properties are Saryarka, the steppe and lakes of Northern Kazakhstan (2008), the Western Tien-Shan (2016, jointly with Kyrgyzstan and Uzbekistan) and the Cold Winter Deserts of Turan (2023, jointly with Turkmenistan and Uzbekistan). This article deals with the cultural properties and with the museums that store, research, interpret and present heritage.

Climate risks, urbanization, growing tourist flows and digitalization have exposed the limits of a purely administrative model of heritage management. European countries that have implemented the 1972 Convention for decades have developed tested tools for this situation. Among them are management plans fixed in national legislation, regular assessment of management effectiveness, involvement of local communities and public-private partnership.

The aim of the article is to analyse the French, Italian and German experience in managing UNESCO properties and museums and to identify how it can be adapted in Kazakhstan. The study is based on a comparative analysis of the normative documents and guidelines of UNESCO and its Advisory Bodies, decisions of the World Heritage Committee and the heritage legislation of France, Italy, Germany and Kazakhstan.

European Experience in Managing World Heritage Properties and Museums

The Operational Guidelines require each World Heritage property to have adequate legal protection, clearly defined boundaries and, where necessary, a buffer zone. Each property also needs an appropriate management plan or other documented management system that specifies how its Outstanding Universal Value (OUV) will be preserved, preferably through participatory means [1, paras 97 to 118]. In European practice the management plan serves as a tool for strategic planning, adaptation and monitoring and is revised as conditions change [3; 4].

The Enhancing Our Heritage Toolkit 2.0, published in 2023 by UNESCO, ICCROM, ICOMOS and IUCN, contains 12 tools for the self-assessment of management effectiveness. It reveals weaknesses in protection, monitoring, resources and stakeholder participation and is recommended for use before a management plan is reviewed or updated [2].

The three countries organize this work differently. In France, the Ministry of Culture acts through its regional directorates (DRAC), and responsibility for World Heritage properties is shared between the State and local authorities. Since the Law of 7 July 2016, article L612-1 of the Heritage Code has required a management plan and a buffer zone for every French World Heritage property [5]. In Italy, Law No. 77 of 20 February 2006 provides for management plans for Italian UNESCO sites and for state funding of their preparation and of visitor services [6]. In Germany, monument protection falls within the competence of the sixteen Länder, each with its own monument protection law, and the Standing Conference of the Ministers of Education and Cultural Affairs (KMK) coordinates World Heritage matters at the national level [7]. These national rules follow the approach of the Operational Guidelines and the Toolkit, which treat a heritage place together with its social, economic and environmental setting and with the participation of local communities [1; 2].

European museums have moved towards professional and more independent management. In Italy this was done through the reform of the Ministry of Culture. Decree of the President of the Council of Ministers No. 171 of 29 August 2014 granted special autonomy to twenty museums, archaeological areas and monumental complexes of national importance, which until then had been offices of the superintendencies without their own directors. These institutions received organizational, scientific and financial autonomy, and their directors were selected through an international public competition in 2015 [14]. European museums have also developed museum education, digitized their collections, opened their data and created virtual exhibitions. They pay growing attention to visitors and to the social role of the museum and combine public funding with grants, sponsorship and their own income from services.

Current State of Cultural Heritage Management in Kazakhstan

The legal framework consists of the Law of the Republic of Kazakhstan “On Culture” of 15 December 2006 No. 207 [9], the Law “On the Protection and Use of Objects of Historical and Cultural Heritage” of 26 December 2019 No. 288-VI [8] and the international conventions ratified by Kazakhstan. Responsibility for heritage protection lies with the Ministry of Culture and Information, local executive bodies and specialized museum-reserves.

Several problems persist in practice. Many sites lack current and functioning management plans, and the number of trained heritage managers is small. Coordination between levels of government and with other stakeholders remains weak. Tourism puts pressure on the Mausoleum of Khoja Ahmed Yasawi in Turkistan and on Tamgaly. Museum collections and documentation are still insufficiently digitized. Recent years have nevertheless brought progress in the form of international internships for museum staff, exhibitions abroad, digitization projects and restoration work with international experts. The nomination of the Rock Mosques and Associated Sacred Sites of Mangystau, inscribed at the 48th session of the World Heritage Committee in Busan in July 2026, was submitted together with a management plan for the property [11].

Directions for Adapting European Experience

1. Management plans should be prepared and regularly updated for all UNESCO properties and key museum-reserves with the help of the Enhancing Our Heritage Toolkit 2.0 [2]. Each plan should set clear objectives for maintaining the OUV and include a monitoring system, tourism management measures, an assessment of climate and anthropogenic risks and mechanisms for community participation.

2. Kazakhstan needs a national coordination centre for World Heritage. Such a centre, with regional branches, could also serve as the secretariat of the National Commission of the Republic of Kazakhstan for UNESCO and ISESCO. German experience shows how a national body can coordinate World Heritage work when responsibility for monuments is divided among several levels of administration. In Germany this role is performed by the KMK [7].

3. The Operational Guidelines recommend preparing management plans through participatory means [1]. For Kazakhstani properties this means involving local residents, holders of traditional knowledge and civil society in drafting and monitoring the plans. At the sacred sites of Mangystau the key partners are the shyrakshy, the traditional custodians who maintain the pilgrimage tradition.

4. Kazakhstani museums need unified digital catalogues of their collections, and heritage sites need 3D documentation. Open data and virtual exhibitions would make heritage more accessible and simplify monitoring.

5. Staff training should become systematic. It can build on the regional UNESCO/ICOM trainings in museum management already held in Kazakhstan [10], add internships at European heritage institutions and introduce standards for museum management and site protection. For the largest national museums, the Italian practice of selecting directors through open international competitions deserves study [14].

6. Heritage financing should draw on public-private partnership, grant programmes, trust funds and tourist levies directed to the protection and interpretation of heritage. The Italian practice of dedicated state funding for management plans can serve as a model [6].

Conclusion

European experience offers Kazakhstan principles and tools that can be adapted to national conditions. The French and Italian practice of making a management plan a legal requirement for each World Heritage property, regular assessment of management effectiveness with the Enhancing Our Heritage Toolkit 2.0 and the German model of national coordination are the most relevant of them. Community participation, digitalization and staff training are the conditions under which these tools work.

Adapting these approaches will improve the protection of UNESCO properties and museums and strengthen their contribution to the development of the regions where they are located. The next steps are applied research and pilot projects at individual sites, beginning with the newly inscribed Mangystau property.

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SMALL MODULAR REACTORS (SMRs): ECONOMIC FEASIBILITY AND PROSPECTS FOR DEPLOYMENT IN KAZAKHSTAN

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Abstract. The article considers small modular reactors (SMRs) as a promising direction of nuclear energy development, characterised by enhanced passive safety and lower up-front investment compared with conventional large nuclear units.

A comparative analysis of leading designs, including RITM-200N, ACP100, BWRX-300 and the NuScale Power Module, is carried out on the basis of IAEA data, with particular attention to the operating experience and safety of Rosatom technologies. The economic part covers capital costs, the levelised cost of electricity (LCOE) and scenarios of its variation.

Using an aggregated techno-economic model and the provisions of the Strategy for the Development of the Nuclear Industry of the Republic of Kazakhstan until 2050, approved by Presidential Decree No. 1233 of 15 April 2026, the study assesses the prospects of SMRs for replacing ageing combined heat and power (CHP) plants. The base-case LCOE of a generalised 300 MW SMR plant is estimated at 65–70 USD/MWh, which is comparable with that of new large nuclear plants.

The study concludes that SMRs are a flexible complement to large power units and an element of the future energy system of Kazakhstan.

Keywords: small modular reactors, SMR, RITM-200N, ACP100, BWRX-300, techno-economic analysis, nuclear energy of Kazakhstan, nuclear industry development strategy.

Introduction

The global energy transition requires simultaneous decarbonisation of the economy, reliable energy supply and reduced dependence on fossil fuels. Under these conditions SMRs attract growing attention as a technological solution that combines the advantages of nuclear generation with greater flexibility, lower investment risk and adaptability to diverse operating conditions.

According to assessments by the International Atomic Energy Agency (IAEA) and the OECD Nuclear Energy Agency (NEA), SMRs make it possible to shorten construction schedules, reduce up-front capital investment and serve smaller grids and non-electric applications [1, 2].

For the Republic of Kazakhstan, which holds some of the world's largest uranium resources and accounted for 43% of world uranium production in 2022 [3], the development of nuclear energy, including small and medium-sized reactor technologies, is of strategic importance.

The 2024 national referendum demonstrated substantial public support for the construction of nuclear power plants [4]. An important step towards implementing this choice was Decree No. 1233, signed by President Kassym-Jomart Tokayev on 15 April 2026, which approved the Strategy for the Development of the Nuclear Industry of the Republic of Kazakhstan until 2050.

The Strategy provides for a techno-economic analysis of SMR applications, including the modernisation of existing CHP plants [5–7].

The aim of this article is to examine the technological features, economic characteristics and deployment prospects of SMRs in Kazakhstan.

Definition and Classification of Small Modular Reactors

The IAEA defines SMRs as reactors with an electrical capacity of up to 300 MWe whose main components are manufactured in factory conditions as modules and then assembled on site [1]. This approach is intended to improve manufacturing quality, shorten construction and reduce up-front investment [1, 2].

The main advantages of the technology are modular design allowing capacity to be added in stages, passive safety systems and reduced site infrastructure requirements. By coolant type, SMRs include pressurised water and boiling water reactors, high-temperature gas-cooled reactors, liquid metal-cooled fast reactors and molten salt reactors. Water-cooled designs represent the most mature technology, since most power reactors in operation today are water-cooled [8].

Comparative Analysis of Leading SMR Technologies

The most advanced SMR projects are being developed and implemented in Russia, China, the United States and Canada [8]. Table 1 compares four water-cooled designs at an advanced stage of development.

Table 1. Key parameters of leading water-cooled SMR designs

Parameter	RITM-200N (Russia)	ACP100 (China)	BWRX-300 (USA, Japan)	NuScale Power Module (USA)
Capacity, MW(e)	55	125	300	77 per module
Reactor type	integral PWR	integral PWR	BWR	integral PWR
Refuelling interval	6 years	24 months	12–24 months	18 months
Design life, years	60	60	60	60
Status in the IAEA Catalogue	detailed design*	under construction**	detailed design	detailed design
Operating prototype	RITM-200 reactors on icebreakers since 2020	none	none	none

*Sources: [8, 9, 11, 12]. * Under construction in Uzbekistan since 2026 [15, 16]. ** Hot functional tests in 2026 [10].*

According to the IAEA Small Modular Reactor Technology Catalogue 2024, close to a hundred SMR designs are known worldwide, of which about 70 active designs with demonstrated sustained development were selected for the Catalogue [1, 8]. Only a few of them have reached operation. Among water-cooled SMRs, the Catalogue lists the Russian KLT-40S as the only design in operation; the operating gas-cooled units are the Chinese HTR-PM and HTR-10 and the Japanese HTTR test reactor [8].

The Russian Federation is represented in the Catalogue by 13 designs, second only to the United States, and is the only country with a water-cooled SMR in operation (Table 2) [8]. Its distinguishing feature is continuity of technology. The RITM series of JSC Afrikantov OKBM is a family of integral pressurised water reactors based on one design and built in versions for icebreakers, floating power units and land-based plants [12, 13]. The series rests on about 400 reactor-years of operating experience with small reactors in the Russian icebreaker fleet [12].

RITM reactors are in serial production. Fifteen RITM-200 units have been completed and thirteen more are in production [14].

Table 2. Russian SMR designs in the IAEA Small Modular Reactor Technology Catalogue 2024

Design	Output, MW(e)	Type	Designer	Status
KLT-40S	2 × 35	Floating PWR	JSC Afrikantov OKBM	In operation
RITM-200N	55	PWR	JSC Afrikantov OKBM	Detailed design*
RITM-200M	50	Floating PWR	JSC Afrikantov OKBM	Detailed design
ABV-6E	9	Floating PWR	JSC Afrikantov OKBM	Detailed design
VBER-300	325	Floating NPP	JSC Afrikantov OKBM	Detailed design
GT-MHR	288	HTGR	JSC Afrikantov OKBM	Basic design
MHR-100	87	HTGR	JSC Afrikantov OKBM	Conceptual design
MHR-T	205.5	HTGR	JSC Afrikantov OKBM	Conceptual design
BREST-OD-300	300	Lead-cooled fast reactor	NIKIET	Under construction
SVBR-100	100	Lead-bismuth fast reactor	JSC AKME Engineering	Detailed design
SHELF	10	Integral PWR	NIKIET	Basic design
UNITHERM	6.6	PWR	NIKIET	Conceptual design
ELENA	0.068	PWR	NRC “Kurchatov Institute”	Conceptual design

*Source: [8]. * Status as given in the Catalogue (3rd edition, June 2025); construction of the first RITM-200N unit in Uzbekistan started in 2026 [15, 16].*

Project Implementation and Safety Performance

SMR safety is based on the defence-in-depth principle, which comprises several independent levels of prevention and mitigation of possible accidents. SMR designs implement it through passive residual heat removal systems relying on natural coolant circulation and gravity, and through a smaller inventory of nuclear material in the core compared with large reactors [1]. For the RITM-200N reactor plant, the design targets are a total probability of severe accidents below 10^{-5} per year and a probability of a major accidental release below 10^{-7} per year. The plant combines inherent safety properties with a balanced use of active and passive safety systems and can follow load in the range of 20–100% of rated power [12].

In the Russian Federation, eight RITM-200 reactors operate on four Project 22220 nuclear icebreakers, Arktika (commissioned in 2020), Sibir (2021), Ural (2022) and Yakutia (2025) [11]. The commissioning of the fifth icebreaker, Chukotka, has been moved to early 2027 [17]. The Akademik Lomonosov floating nuclear power plant in Pevek, equipped with two KLT-40S reactors of 35 MWe each, has been in commercial operation since May 2020. It reached its first billion kilowatt-hours of electricity in January 2025 and had generated more than 1.2 TWh by 2026 [18, 19].

In the People's Republic of China, the HTR-PM high-temperature gas-cooled reactor has been in commercial operation since December 2023, demonstrating the commercial operation of a Generation IV technology [20].

Of direct relevance to Central Asia is the construction of Uzbekistan's first nuclear power plant in the Jizzakh Region. A construction licence for the first RITM-200N unit was issued in June 2026, first concrete was poured in the same month, and the unit is scheduled to reach criticality in late 2029. The plant combines two 55 MWe RITM-200N units with two VVER-1000 units, with a total capacity of more than 2.1 GW, and is a direct precedent for Kazakhstan [15, 16].

This experience confirms the technical maturity and safety of the water-cooled SMRs in operation and justifies their consideration for Kazakhstan.

Economic Analysis of Small Modular Reactors

The economic feasibility of SMRs is determined by capital costs, operating expenses, the fuel component and long-term cost reduction through serial production and learning effects. Specific capital costs of SMRs are higher than those of large nuclear power plants because of the loss of economies of scale, which modularisation and serial production are expected to offset [2]. A bottom-up assessment of a light-water SMR plant gives a mean overnight cost of 5,233 USD/kW (90% interval 4,254–6,399 USD/kW) and a construction period of 3.4–6.0 years [21].

As a reference point for the cost of electricity, the median LCOE of new large nuclear plants at a 7% discount rate is 69 USD/MWh [22]. The fuel component accounts for a small share of the total costs of nuclear generation, which is an advantage for Kazakhstan as a uranium-producing country [3].

The authors' simplified techno-economic model considers a generalised 300 MW SMR plant consisting of several modules. With capital costs of 1.8 billion USD (6,000 USD/kW, within the range given in [21]), a capacity factor of 90%, a service life of 60 years and a discount rate of 7%, the base-case LCOE is 65–70 USD/MWh. Operating and fuel costs are taken from generalised international data. The result is comparable with the median LCOE of new large nuclear plants [22]. Table 3 shows the sensitivity of the result to capital costs and construction time.

Table 3. Scenario analysis for a generalised 300 MW SMR plant (authors' calculations)

Scenario	LCOE, USD/MWh
Base	68
Optimistic (20% capital subsidy)	55
Pessimistic (construction delays and 20% higher capital costs)	85

The estimates are aggregated. Project decisions require site-specific data on costs, tariffs and financing.

Thorium-containing fuel is not included in the calculations and is considered a long-term research direction. The authors' earlier work addresses the techno-economic assessment of thorium recovery from monazite ores and REE tailings under Central Asian conditions [23] and partial thorium loading of VVER-1000/1200 reactors [24].

Prospects for SMR Deployment in Kazakhstan

Kazakhstan has several advantages for deploying SMRs. Its uranium resource base and production capacity provide a basis for localising stages of the fuel cycle [3].

Kazakhstan also possesses thorium-bearing resources associated with uranium deposits. According to the authors' estimates, thorium resources in Kazakhstani uranium tailings exceed 15,000 t Th, and integrating thorium recovery into existing hydrometallurgical circuits could reduce marginal extraction costs to 80–120 USD/kg ThO_2 [23].

The Strategy for the Development of the Nuclear Industry until 2050 emphasises the diversification of nuclear technologies and considers SMRs one of the instruments for modernising

CHP plants and improving the overall efficiency of the energy system [5, 6]. SMRs combine reliable baseload generation with heat cogeneration, which is relevant for industrial enterprises and urban infrastructure.

Cooperation with two or three leading international vendors (Rosatom, China National Nuclear Corporation, GE Hitachi or NuScale) would reduce technological and political risks, ensure competition and allow the selection of technical solutions suited to the climatic and industrial conditions of Kazakhstan.

Among these vendors, Rosatom has the most extensive operating experience (Table 2). The RITM-200N belongs to a reactor family in serial production and operation, and its first unit is under construction in neighbouring Uzbekistan [15, 16]. In addition, Rosatom leads the project for Kazakhstan's first large nuclear power plant [25]. This makes the RITM-200N a natural reference technology for a Kazakhstani pilot project, as it would allow shared personnel training, supply chains and regulatory practice with the Uzbek project and the large nuclear power plant.

Mastering SMRs will support new scientific and engineering fields in Kazakhstan, including localisation of equipment manufacturing, cogeneration systems, digital control systems and research on thorium fuel [23, 24].

Discussion and Conclusions

Several SMR designs, primarily water-cooled, have reached technological maturity. Russia operates KLT-40S and RITM-200 reactors, China operates the HTR-PM, and Uzbekistan has begun construction of a RITM-200N plant in conditions close to those of Kazakhstan.

The authors' estimates give a base-case LCOE for a generalised 300 MW SMR plant that is comparable with that of new large nuclear plants. The result is highly sensitive to capital costs and construction time. Because the model is aggregated and does not use site-specific data, the cost risk of first-of-a-kind units remains the main uncertainty.

In Kazakhstan, SMRs can complement large power units. They reduce the up-front investment of each project, increase the flexibility of the energy system and provide heat cogeneration for industry and municipal services. The Strategy for the Development of the Nuclear Industry until 2050 provides the policy basis for such projects [5, 6].

The analysis points to the following next steps.

1. A detailed techno-economic assessment of replacing ageing urban CHP plants with SMRs on the basis of site-specific data, including cogeneration and full life-cycle costs.
2. Selection of a reference technology and a site for a pilot project. Given its operating basis on the RITM-200 icebreaker reactors and the regional precedent in Uzbekistan, the RITM-200N is a natural candidate.
3. Further development of the national regulatory framework in line with IAEA standards and localisation of fuel cycle stages, including long-term research on thorium fuel.
4. Development of financial mechanisms, such as state guarantees and tax incentives, that reduce the cost of capital for SMR projects.

SMRs are energy systems of the future. Modularity, passive safety and the ability to supply both electricity and heat make them suitable for remote areas, smaller grids and industrial heat consumers [1, 2]. As the first units in Russia, China and Uzbekistan accumulate operating experience, Kazakhstan, with its uranium resource base and long-term nuclear strategy, has the conditions to include SMRs in the future structure of its energy system.

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Geographic Sciences

ENVIRONMENTAL IMPACT AND MANAGEMENT PROBLEMS OF MUNICIPAL WASTE IN AZERBAIJAN

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Abstract. Waste generation inflicts severe damage on the environment, human health, and ecosystems. However, this issue can be minimized through proper management and shifts in individual habits. Plastic waste dumped into oceans and forests causes the deaths of millions of marine animals and birds each year. Animals ingest plastic, mistaking it for food, or perish after becoming entangled in it. Research indicates that the solution to this problem should not be confined solely to the actions of government agencies and relevant enterprises, but must encompass all segments of society. Raising public ecological awareness, reshaping consumption culture, reducing the use of single-use plastic products, and sorting waste at its source are vital steps in this direction. In particular, integrating the "3Rs" principles – Reduce, Reuse, and Recycle – into daily life can decrease waste volume and enable a more efficient utilization of natural resources.

Keywords: household waste, ecosystem, debris, recycling, waste separation

Waste management in Azerbaijan has emerged as one of the state's core priorities, particularly in recent years. Currently, significant infrastructure initiatives are being undertaken across both the capital city of Baku and the regions to align waste management practices with European standards.

Waste generation inflicts severe damage on the environment, human health, and ecosystems. However, this issue can be minimized through proper management and shifts in individual habits.

Plastic, battery, and chemical wastes do not decompose when buried in landfills. The toxic substances they contain leach into groundwater and soil, contaminating agricultural products. Furthermore, the decomposition of organic waste accumulated in landfills releases methane (CH_4), a potent greenhouse gas. Additionally, the incineration of waste emits carbon monoxide and carcinogenic substances into the atmosphere.

Plastic pollution is one of the most serious environmental challenges facing the world today. Every year, enormous quantities of plastic waste enter oceans, forests, rivers, and other natural ecosystems, causing devastating and often irreversible damage. Millions of marine animals and birds die as a result of plastic pollution. Animals frequently mistake plastic for food and swallow it, leading to injury, starvation, and death, while others become entangled in plastic waste and are unable to escape.

The environmental impact does not end there. Over time, larger plastic materials break down into tiny particles known as microplastics. These particles contaminate water, soil, and ecosystems and can enter the food chain, eventually reaching the human body. As a result, plastic

pollution is not only a threat to wildlife and the environment but also a growing concern for human health.

Addressing this global crisis requires urgent and coordinated action at both national and international levels. Governments, businesses, and individuals must work together to reduce plastic consumption and improve waste management. The internationally recognized "3R" principle – Reduce, Reuse, Recycle – should become a fundamental part of environmental policy and everyday life. By reducing unnecessary consumption, reusing materials whenever possible, and ensuring effective recycling, we can decrease the amount of waste entering the environment and help protect ecosystems for future generations.

Measures at the Government and Industrial Levels

- **Establishment of Recycling Plants:** Recycling paper, glass, metal, and plastic and reintroducing these materials into the production cycle.
- **Introduction of a Deposit-Return System:** Establishing collection points where people can return plastic and glass containers in exchange for a monetary refund. This system encourages people to sort and recycle their waste rather than dispose of it improperly.
- **Biodegradable Materials:** Banning single-use plastic containers and replacing them with packaging made from cardboard or starch-based materials that decompose naturally and more quickly in the environment

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What Can We Do?

- **Developing the Habit of Waste Sorting:** Separating household waste into different categories – plastic, paper, glass, and food waste – and placing them in the appropriate recycling or waste-sorting bin.
- **Reducing Plastic Use:** Using reusable **cloth bags (eco-bags)** instead of plastic shopping bags and reusable thermoses or travel mugs instead of disposable coffee cups.
- **Composting:** For people with a garden or backyard, converting food scraps and fruit and vegetable waste into natural fertilizer (compost)

Waste management in Azerbaijan has become one of the government's key priorities, particularly in recent years. Significant infrastructure measures are currently being implemented both in the capital, Baku, and across the regions to bring the country's waste management system closer to European standards

Volume of Waste Generated: According to official figures, more than approximately 4.4 million tonnes of waste are generated annually in Azerbaijan. Around 73.5% of this consists of municipal solid waste (household waste), while the remainder consists of industrial waste generated by enterprises [2].

To coordinate waste management through a centralized system, the State Agency for Waste Management under the Ministry of Ecology and Natural Resources has been established, and a new National Strategy covering the period 2027–2030 is currently being developed [1].

In the city of Baku and the surrounding settlements, the disposal and management of municipal solid waste are primarily carried out by "Tamiz Shahar" JSC. Within this framework, several large-scale waste management and treatment facilities are in operation

Baku Municipal Solid Waste Incineration Plant (Balakhani): The plant is one of the largest and most modern facilities in Eastern Europe and the CIS, built using fourth-generation (4G) technology. Its annual processing capacity is 500,000 tonnes of municipal solid waste and 10,000 tonnes of medical waste.

The waste incineration process generates approximately 200–222 million kWh of electricity annually. This amount of energy is sufficient to fully meet the electricity needs of approximately 100,000 households. The plant is operated by the French company *PAPREC Énergies*, drawing on international expertise.

The waste delivered to the plant is sorted according to its type, including plastic, paper, glass, ferrous metals, and non-ferrous metals

The main objective is to reduce the overall volume of waste, separate recyclable materials, and create an affordable raw material supply for other recycling facilities in Baku. The plant has an annual processing capacity of 200,000 tonnes.

The Balakhani Industrial Park (Recycling Facilities) was established near the Balakhani landfill. A number of privately owned recycling companies operate within the park. Here, sorted plastic containers, used engine oils, paper and cardboard products, and rubber tyres are recycled and transformed into new products.

The Waste Management Centre LLC (Hazardous Waste Landfill), operating under the Ministry of Ecology and Natural Resources, is also in operation. With the exception of radioactive materials, the centre ensures the environmentally safe treatment and disposal of drilling mud, soil contaminated with oil and chemicals, expired food products, and special medical and toxic waste. These materials are subsequently disposed of in designated landfill sites.

Although waste management in Baku has been centralized, waste sorting and separation systems in the regions are not yet fully operational, and waste disposal sites largely remain open landfills. However, the government has introduced the Public-Private Partnership (PPP) model to address this challenge.

For example, according to approved regional projects, plans are underway to establish a modern sanitary landfill and waste transfer stations in the Guba-Khachmaz economic region, with the capacity to manage 170,000 tonnes of waste annually. Similar projects are also planned for other economic regions of the country.

The Nakhchivan Autonomous Republic is currently undergoing a period of fundamental reforms in the field of waste management. For many years, waste in the region was primarily transported to open landfills for disposal. However, in recent years, modern green technologies and waste management models implemented in Baku have also been introduced in Nakhchivan.

According to official information, approximately 151,000 tonnes (631,000 cubic metres) of municipal solid waste and medical waste are generated annually in the Nakhchivan Autonomous Republic [2].

A special landfill project for the disposal of hazardous waste is being implemented on a nine-hectare site in the village of Boyukduz, Kangarli District. Topographical surveying work is currently underway at the site.

To promote a culture of recycling among the population, environmental campaigns such as “Exchange Waste for Saplings” are organized in the region. Residents hand over collected plastic and glass waste, as well as used batteries, and receive various tree saplings in return.

Major infrastructure projects have been launched in Nakhchivan with the aim of significantly improving environmental conditions and ensuring the efficient use of waste resources.

The Ministry of Ecology and Natural Resources of the Nakhchivan Autonomous Republic plans to construct a municipal solid waste processing and waste-to-energy plant. This facility is expected to serve as a regional counterpart to the Balakhani Waste Incineration Plant in Baku.

As part of the project, design and cost-estimation documentation is being prepared for the construction of one central waste landfill that fully meets modern sanitary standards, as well as four regional waste transfer stations, each covering an area of one hectare, to collect waste from different districts of the autonomous republic.

At the initial design stage, plans include the installation of modern sorting lines at the future facility to separate paper, glass, and plastic materials for recycling.

Special regional sanitary and hygiene regulations have been approved in Nakhchivan to govern the collection and transportation of waste. Under these regulations, the temporary storage and transportation of waste, as well as the regular disinfection of waste containers in multi-storey residential buildings, military facilities, and hospitals (medical waste), are subject to strict supervision.

The management, collection, sorting, transportation, and disposal of medical waste in the Nakhchivan Autonomous Republic are regulated in accordance with Decision No. 213 of the Cabinet of Ministers of the Republic of Azerbaijan on the "Requirements for the Management of Medical Waste" and applicable regional environmental and sanitary standards.

The Public Health Service, operating under the Ministry of Health of the Nakhchivan Autonomous Republic, regularly conducts inspections and monitoring to ensure compliance with these regulations.

The Rules and Specific Requirements Governing Safe Waste Disposal and Treatment (Neutralization) Are as Follows:

1. Classification of Medical Waste (Categories)

All waste generated in healthcare and medical institutions is divided into **four main categories** according to its level of hazard. Mixing waste from different categories is strictly prohibited.

- **Class A (Non-Hazardous):** Waste from hospital wards that has not come into contact with patients suffering from infectious diseases, including paper and food waste. It is collected in **white bags**.
- **Class B (Hazardous):** Biological fluids (blood, serum), human body parts, and waste generated by surgical and infectious disease departments. It is collected in **yellow bags**.
- **Class C (Extremely Hazardous):** Waste generated by tuberculosis dispensaries, laboratories, and departments working with pathogenic microorganisms belonging to Groups 1–4. It is collected in **red bags**.
- **Class D (Industrial-Type Waste):** Expired medicines, mercury-containing devices (such as thermometers), and chemical disinfectants.

2. Packaging and Waste Sorting Regulations

- **Leak-Proof Packaging:** Biological and infectious materials belonging to Classes B and C must be placed exclusively in strong, hermetically sealed, leak-proof bags. Once the bags are filled to a maximum of **three-quarters (3/4) of their capacity**, they must be securely sealed.
- **Sharp and Cutting Instruments:** Syringes, needles, ampoules, and scalpels must never be disposed of in ordinary waste bags. They must be collected in specially designed **puncture-resistant yellow plastic containers (sharps boxes)**.
- **Labelling:** Each filled bag or container must be provided with a label indicating the department name, waste category, date, and signature of the person responsible.

3. Temporary Storage and Transportation Procedures

- **Time Limits:** Medical waste may be stored within the healthcare facility for a maximum of 24 hours at room temperature (under normal environmental conditions), or for up to 48 hours in specially designed refrigeration units at temperatures of up to **+5°C**.
- **Location Requirements:** Temporary waste collection areas or designated outdoor storage sites must be located at least 50 metres away from the main healthcare building. Access to these areas by unauthorized persons is strictly prohibited.
- **Specialized Transportation:** Waste must be transported exclusively using specially designated vehicles that are disinfected, fully enclosed, and hermetically sealed. During

transportation, any direct contact between waste and workers' hands or bodies must be completely avoided.

4. Methods of Waste Treatment and Disposal

The direct disposal of medical waste, particularly Class B and Class C waste, in municipal landfills is prohibited by law. Pathogenic waste collected from healthcare facilities is neutralized using the following methods:

1. Thermal Treatment (Incineration): Waste is completely burned at high temperatures in specialized incinerators and converted into ash.
2. Chemical and Steam Sterilization (Autoclaving): Waste is treated using chemical disinfectants or high-pressure saturated steam to eliminate pathogenic microorganisms and render it safe for further disposal.
3. Waste Picking (Scavenging): The practice of people searching through waste at landfills or in municipal waste containers, often referred to as “scavenging” or informal waste picking, represents a serious socioeconomic, public health, and environmental challenge. This phenomenon is observed in many developing countries around the world, including, to some extent, Azerbaijan.

4. The causes of waste picking, the risks it creates, and possible solutions can be grouped as follows:

Factors That Force People to Scavenge Through Waste

- Economic Hardship and Poverty: Low-income or unemployed individuals collect recyclable materials (plastic bottles, cardboard, metal, and aluminium cans) and sell them on informal raw material markets to earn a living and support themselves.
- Food Supply: In some cases, homeless or socially vulnerable individuals search through waste bins near supermarkets and restaurants in an attempt to collect discarded food that still appears suitable for consumption.
- An Unregulated Informal Sector: The lack of waste separation at the source (households) creates a kind of informal workplace for these individuals. They sort through waste, recover valuable materials, and sell them through unofficial or illegal channels.

Dangers and Risks Associated with This Practice

1. Risks to Human Health

- Infectious Diseases: In addition to household waste, waste bins sometimes contain improperly disposed of medical waste (needles, dressings) or animal carcasses. Contact with such materials exposes waste pickers to serious infections, including Hepatitis B, Hepatitis C, HIV/AIDS, tuberculosis, and severe skin diseases.
- Poisoning: Consuming expired food products or coming into direct contact with hazardous chemical waste can lead to acute poisoning.
- Physical Injuries: Broken glass, sharp metal objects, and rusty nails can cause serious physical injuries and increase the risk of tetanus infection.

2. Environmental and Social Problems

- Scattering of Waste into the Surrounding Environment: People searching through waste containers often tear open rubbish bags and scatter their contents on the ground. This creates unsanitary conditions, contributes to street pollution, causes unpleasant odours, and encourages the proliferation of rodents, particularly rats.
- Social Marginalization: Individuals engaged in this activity, particularly children and adolescents, are often excluded from education and normal social life, further increasing their vulnerability to poverty and social isolation.

Solutions and Measures to Address the Problem

Addressing this problem requires both social assistance programmes and improvements in waste management systems.

- **Mandatory Waste Separation at Source:** If paper, plastic, and glass are collected separately in designated household bins, valuable recyclable materials will no longer be mixed with general waste. This would reduce the incentive and perceived need for people to search through rubbish containers.
- **Smart and Enclosed Waste Containers:** Installing underground waste containers or specially designed, secure bins with restricted access, as implemented in European countries and on some central streets of Baku, would prevent unauthorized access to their contents and discourage people from rummaging through waste.
- **Social Support and Formal Employment:** Individuals who collect plastic and other recyclable materials from waste containers could be officially registered and provided with social assistance or recruited by recycling plants (such as the Balakhani Waste Sorting Plant) as formally employed workers. They should be provided with safe working conditions and appropriate protective equipment, including masks and gloves.
- **Establishment of Food Banks:** A formal food donation system (Food Banking) should be established, allowing supermarkets to donate unsold food products that are still safe for consumption to shelters and people in need rather than throwing them away.

Some of the world's most successful models for integrating waste pickers (scavengers) into the formal labour market and organizing them into cooperatives have been implemented in Brazil, Colombia, and Pune, India. By formalizing the informal waste collection sector, these countries have significantly increased recycling rates while providing thousands of low-income citizens with stable incomes, health insurance, and safer working conditions.

International organizations, including the World Bank and the WIEGO (Women in Informal Employment: Globalizing and Organizing) network, recommend these models as important examples of green economy practices that can be adopted by other developing countries.

The Brazilian Model: The “Catadores” Movement

Brazil was one of the first and most advanced countries to formally integrate street waste pickers, locally known as *catadores*, into the national waste management system.

- **Official Recognition as an Occupation:** In 2001, waste picking was officially included in Brazil's national occupational classification system.
- **Establishment of Cooperatives:** Workers organized themselves into strong associations and formally registered recycling cooperatives.
- **Municipal Service Contracts:** Under the relevant legislation, municipalities can enter into direct service agreements with waste picker cooperatives to manage municipal waste, rather than relying exclusively on private monopoly companies.
- **National Policy (2010):** Under the National Solid Waste Policy adopted in 2010, the participation of informal waste workers in recycling activities is legally protected, and producers are required to cooperate with them.

The Colombian (Bogotá) Model: Legal Recognition and Stable Remuneration

In Bogotá, the capital of Colombia, the struggle of waste pickers achieved a significant victory at the level of the Constitutional Court.

- **Court Ruling:** Colombia's Constitutional Court imposed an obligation on the municipality to formally include waste pickers in the city's sanitation and waste management planning.
- **Payment for Services:** The Bogotá city administration has established formal agreements with waste picker organizations. Workers receive official payments at fixed rates from the municipal budget for every tonne of recyclable materials they collect.

• **Occupational Safety Support:** Workers are provided by the government with official uniforms, protective masks, gloves, and specialized vehicles for transporting collected materials.

The Indian (Pune) Model: The "SWaCH" Cooperative

The model implemented in Pune, India, is based on direct cooperation between informal waste workers and local residents.

• **Door-to-Door Collection:** Workers collect waste directly from households and officially charge residents a small service fee.

• **Municipal Support and Benefits:** The Pune Municipal Corporation provides workers with designated enclosed waste-sorting facilities, official identification cards, and free health insurance.

• **Economic Growth:** As a result of this system, the municipality's waste transportation costs have decreased significantly, while the monthly incomes of waste pickers have increased approximately 2.5 times.

The South African (Johannesburg) Model

In Johannesburg, partnership centres have been established to promote cooperation between informal waste workers and the government.

• **Joint Recycling Centres:** Special recycling centres have been established as collaborative projects between the municipality and waste picker associations.

• **Infrastructure and Facilities:** The government provides modern warehouses and conveyor-based sorting lines, moving workers away from hazardous open dumpsites and enabling them to work in cleaner and safer conditions.

According to official statistics and environmental monitoring reports, Sadarak District is the cleanest administrative district in Azerbaijan in terms of air pollution, with no recorded emissions of pollutants into the atmosphere [3].

More broadly, regions with fewer large industrial facilities, lower traffic density, and a higher proportion of green spaces are considered among the most environmentally clean areas of the country. These include Eastern Zangazur, the mountainous parts of Karabakh, the border areas of Nakhchivan, the Shaki-Zagatala region, and the Guba-Gusar region.

Based on air quality, low levels of industrial emissions, and the criteria established by the World Health Organization (WHO), the following areas are identified as having some of the cleanest environmental conditions in Azerbaijan [7]:

1. Districts with the Cleanest Atmospheric Air (Official Statistics)

According to reports published by the State Statistical Committee of Azerbaijan, the districts with the lowest levels of air pollutants released by industrial enterprises are ranked as follows:

• **Sadarak District:** The only district in the country where industrial emissions into the atmosphere are recorded at **0 tonnes**.

• **Fuzuli District:** Annual emissions of just 0.3 tonnes.

• **Kangarli District:** Annual emissions of 0.4 tonnes.

• **Yardimli District:** Annual emissions of 0.8 tonnes.

• **Zardab District:** Annual emissions of 1.4 tonnes.

• **Tartar District:** Annual emissions of 1.6 tonnes [4].

2. The Cleanest Regions from a Geographical and Environmental Perspective

According to international environmental reports (such as the WHO's interactive air quality maps), the city of Shusha and the Lachin District stand out for their exceptionally high air quality, based on the concentration of microscopic pollutants per cubic metre of air. Overall, the following mountainous districts rank among the areas with the cleanest air in the country:

• **Yardimli and Gadabay:** Their clean air quality is largely attributed to extensive forest coverage and the absence of major industrial facilities.

• **Gusar and Gakh:** These areas benefit from high-altitude mountain ecosystems.

• **Lachin, Kalbajar, and Shusha:** These regions are distinguished by natural spring waters, extensive forests, and limited exposure to industrial pollution.

3. Environmental Conditions Around Baku and in Major Cities

Among Azerbaijan's major cities, the capital, Baku, experiences the highest levels of pollution due to heavy traffic and dense urban development. However, certain suburban areas benefit from favourable air circulation and relatively clean atmospheric conditions.

For example, on the Absheron Peninsula, Bilgah, Mardakan, Novkhani, and Pirshagi are considered some of the cleanest residential and garden areas, as they are directly influenced by the northerly Khazri winds from the Caspian Sea.

Research indicates that addressing the waste management problem should not be limited to the activities of government agencies and relevant enterprises; rather, it must involve all segments of society. Raising public environmental awareness, changing consumption habits, reducing the use of single-use plastic products, and sorting waste at its source are essential steps in this direction [5; 6].

In particular, applying the **"3R" principle – Reduce, Reuse, Recycle –** in everyday life can help decrease the overall volume of waste and promote more efficient use of natural resources.

Thus, improving the efficiency of Azerbaijan's waste management system is of great importance for ensuring environmental safety, preserving natural resources, and achieving sustainable development goals. The implementation of a comprehensive government policy in this field, the improvement of legislative mechanisms, the expansion of modern waste processing infrastructure, and the promotion of environmental responsibility can significantly reduce the negative impact of waste on the environment in the future.

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ANTROPOSEN DÖVRÜ: İNSAN ƏLİ İLƏ YARADILAN RELYEF FORMALARI VƏ ANTROPOGEN GEOMORFOLOGİYA

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Xülasə

Bu məqalədə insanın yer kürəsinin geoloji və geomorfoloji proseslərinə göstərdiyi qlobal təsirlər Antroposen paradiqması kontekstində təhlil edilir. Klassik coğrafiyada relyefəmələgəlmə prosesləri yalnız təbii endogen və ekzogen qüvvələrin fəaliyyəti kimi öyrənilsə də, müasir dövrdə insan fəaliyyəti texnogen relyefin formalaşmasında aparıcı amilə çevrilmişdir. Tədqiqat çərçivəsində Dubaydakı Palma adaları kimi süni strukturlaşdırılmış sahil relyef formaları, Niderlandın polder sistemləri və dəniz səviyyəsindən aşağı salınan bəndləri, nəhəng karyerlər və dağ-mədən fəaliyyətinin yaratdığı antropogen depressiyalar, həmçinin okeanlarda plastik tullantıların akkumulyasiyası nəticəsində yaranan "yeni qitələr" (məsələn, Böyük Sakit Okean Zibil burulğanı) kompleks şəkildə araşdırılır. İnsanın geomorfoloji bir qüvvə kimi təbii relyef dinamikasını üstələməsi və "Yeni Coğrafiya" anlayışının formalaşması məqalənin əsas elmi istiqamətini təşkil edir.

Açar sözlər: Antroposen, Yeni Coğrafiya, Antropogen Geomorfologiya, Süni Adalar, Polderlər, Texnogen Relyef.

Giriş

XIX əsrin sonlarından etibarən sənayeləşmənin sürətlənməsi, urbanizasiya və demoqrafik artım bəşəriyyətin təbiət üzərindəki təsir imkanlarını misilsiz dərəcədə genişləndirmişdir. Coğrafiya elmində uzun onilliklər boyu hakim olan klassik yanaşmaya görə, yer səthinin relyefi — dağlar, dərələri, çay şəbəkələri və düzənliklər — daxili (endogen) və xarici (ekzogen) təbii qüvvələrin çoxəsrlik qarşılıqlı təsirinin məhsuludur. Lakin XXI əsrin elmi paradiqması yer kürəsinin tamamilə yeni bir geoloji epoxaya — Antroposen (İnsan əsri) dövrünə qədəm qoyduğunu qəbul edir. Nobel mükafatı laureatı Paul Krutzen tərəfindən elmi dövriyyəyə daxil edilən Antroposen termini, insanın artıq sadəcə bioloji bir növ deyil, həm də qlobal geoloji və geomorfoloji dəyişikliklərə səbəb olan super-qüvvəyə çevrildiyini ifadə edir.

Bu kontekstdə "Yeni Coğrafiya" və ya Antropogen Geomorfologiya istiqaməti formalaşmaqdadır. Müasir dövrdə insanların hər il yerini dəyişdirdiyi süxur, qrunt və çöküntülərin həcmi, bütün dünya çaylarının və tektonik hərəkətlərin daşıdığı materialın ümumi həcmindən qat-qat çoxdur. İnsan fəaliyyəti təbii relyef formalarını transformasiya etməklə yanaşı, təbiətdə analoqu olmayan yeni, süni relyef vahidləri yaradır. Bu məqalə, insan əli ilə yaradılan irimiqyaslı geomorfoloji strukturları təhlil edərək, Yeni Coğrafiyanın landşaft arxitekturasını və onun gələcək fəsadlarını elmi aspektdə işıqlandırmağı hədəfləyir.

- **Sahil Geomorfologiyasının Texnogen Transformasiyası: Dubay Süni Adaları**

İnsanın dəniz və okean akvatoriyalarında relyefəmələgəlmə proseslərinə müdaxiləsinin ən bariz və vizual nümunəsi Birləşmiş Ərəb Əmirliyinin Dubay şəhərində həyata keçirilən irimiqyaslı süni adalar layihələridir. Xüsusilə "Palma Cumeyra" (Palm Jumeirah) və "Dünya adaları" (The World) kimi meqa-strukturlar antropogen akvatoriyal relyefin zirvəsi hesab olunur.

Bu adaların inşası dəniz dibindən milyonlarla kubmetr qum və daş materialının xüsusi gəmilər (drajlar) vasitəsilə çıxarılması və geodezik kordinatlara uyğun olaraq yenidən çökdürülməsi prosesinə (land reclamation) əsaslanır. Bu proses təbii litodinamik axınları, sahilboyu dalğa rejimini

və sedimentasiya (çökmə) balansını kökündən dəyişdirir. Süni olaraq yaradılan bu geomorfoloji vahidlər sahil xəttini onlarla kilometr uzadır və dəniz ekosisteminə yeni relyef elementləri əlavə edir. Lakin bu cür süni relyef formaları yüksək dərəcədə qeyri-sabitdir; onlar təbii erroziyaya və dəniz cərəyanlarının dağıdıcı təsirinə qarşı davamlılığı saxlamaq üçün daimi mühəndis nəzarəti və süni bərkitmə tədbirləri tələb edir. Bu da öz növbəsində relyefin "canlı", daimi antropogen asılılıqda olan bir sistemə çevrildiyini sübut edir.

- Dəniz Səviyyəsindən Aşağı Landşaftların Yaradılması: Niderlandın Polder Sistemləri

Əgər Dubayda insan dənizə doğru irəliləyərək müsbət relyef formaları yaradırsa, Niderlandda proses tam əksinə — dəniz səviyyəsindən aşağıda mənfi və hamar antropogen landşaftların formalaşdırılması şəklində baş verir. Niderland ərazisinin təxminən 26%-i dəniz səviyyəsindən aşağıda yerləşir və bu ərazilər silsilə mühəndis-texniki bəndlər, kanallar və nasos stansiyaları vasitəsilə qurudulmuş körfəz və bataqlıqlardır ki, bunlara "polderlər" deyilir.

Şimal dənizinin hidrodinamik təzyiqinin qarşısını alan nəhəng bəndlər (məsələn, Zuiderzee layihəsi və Delta Planı) regional geomorfoloji strukturu tamamilə dəyişmişdir. İnsanlar minilliklər boyu davam edən dəniz sedimentasiyasını dayandırmış, keçmiş dəniz dibini kənd təsərrüfatı və urbanizasiya üçün antropogen düzənliklərə çevirmişlər. Bu proses geomorfoloji baxımdan unikal fenomen yaradır: təbii olaraq su altında qalmalı olan depressiyalar insan fəaliyyəti sayəsində quru relyefi kimi fəaliyyət göstərir. Bu landşaftların qorunması antropogen mühəndislik fəaliyyətinin fasiləsizliyindən birbaşa asılıdır.

- Litosferdə Açılan Yaralar: Nəhəng Karyerlər və Dağ-mədən Relyefi

İnsanın litosferin üst qatına birbaşa mexaniki təsiri dağ-mədən sənayesində və faydalı qazıntıların açıq üsulla hasilatında özünü büruzə verir. Dünyanın ən böyük texnogen mənfi relyef formaları məhz karyerlərdir. Məsələn, ABŞ-dakı "Bingem Kanyonu" (Bingham Canyon) mis karyerinin dərinliyi 1.2 kilometrdən, eni isə 4 kilometrdən çoxdur. Oxşar şəkildə Şərqi Sibirdəki "Mir" almaz karyeri yer qabığında nəhəng bir qıf forması yaratmışdır.

Bu cür meqa-karyerlərin qazılması təbii dağ massivlərinin geomorfoloji strukturunu məhv edir, yamacların dayanıqlığını pozur və sürüşmə, uçqun kimi ekzogen prosesləri süni şəkildə aktivləşdirir. Karyerlərlə yanaşı, hasilat prosesində çıxarılan tullantı süxurların üst-üstə qalanması nəticəsində müsbət relyef formaları — süni təpələr olan "terrikonlar" yaranır. Beləliklə, dağ-mədən rayonlarında təbii geomorfoloji landşaft tamamilə sıradan çıxaraq, yerini kəskin parçalanmış texnogen sirk və amfiteatrlara, terraslaşdırılmış süni yamaclara verir.

- Okeanlarda Antropogen "Yeni Qitələr": Plastik Tullantıların Akkumulyasiyası

Antroposen dövrünün ən acınacaqlı və qeyri-adi ekoloji-geomorfoloji təzahürlərindən biri dünya okeanlarında formalaşan plastik tullantı adalarıdır. Okean cərəyanlarının (subtropik burulğanların) təsiri ilə mərkəzə doğru toplanan milyonlarla ton plastik tullantı, geomorfoloji mənada litoloji deyil, "plastik" tərkibli yeni üzən massivlər formalaşdırır. Bunun ən böyük nümunəsi "Böyük Sakit Okean Zibil Burulğanı"dır (Great Pacific Garbage Patch). Belə sahələrin ümumi sahəsi bəzi qitə və ya böyük dövlətlərin ərazisini üstələyir.

Bu strukturları şərti olaraq "yeni qitələr" adlandırmaq elmi baxımdan okean sedimentasiyasında yeni bir litoloji qatın — plastiklərin, çöküntü süxurları ilə birləşərək "plastiglomerat" adlanan yeni süxur növünün yaranması ilə əlaqədardır. Sahil relyefində və okean dibində toplanan bu materiallar gələcəyin geoloji qatlarında insanın izi kimi qalacaqdır. Okeanın hidrodinamikasına birbaşa quru relyefi kimi təsir etməsələr də, günəş şüalarının udulmasını və buxarlanma rejimini dəyişdirərək lokal okean-atmosfer qarşılıqlı təsirinə təsir göstərirlər.

- Nəticə və Gələcək Perspektivlər

Təhlil edilən nümunələr göstərir ki, Antroposen dövründə relyefəməlgəlmə artıq yalnız təbiətin kor təbii qüvvələrinin deyil, həm də insan ağlının və texnoloji gücünün idarə etdiyi bir prosesdir. İnsan əli ilə yaradılan süni adalar, polderlər, nəhəng karyerlər və plastik sedimentasiya

sahələri geomorfologiya elminin sərhədlərini genişləndirərək "Yeni Coğrafiya" anlayışını zəruri mənimsəmə obyektinə çevirmişdir.

Lakin bu texnogen relyef formalarının yaradılması çox vaxt təbii ekoloji və geomorfoloji tarazlığın pozulması ilə müşayiət olunur. Qlobal iqlim dəyişikliyi və dünya okeanının səviyyəsinin qalxması fonunda mühəndislik asılılığı olan bu relyef formalarının (xüsusilə polderlərin və süni adaların) gələcək davamlılığı ciddi sual altındadır. Bəşəriyyət yer səthini yenidən formalaşdırarkən təbiətin fundamental qanunlarını nəzərə almalı, antropogen geomorfologiyanı ekoloji dayanıqlılıq prinsipləri ilə uzlaşdırmalıdır.

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Architecture

ИНТЕГРАЦИЯ ГЕОИНФОРМАЦИОННЫХ И BIM-ТЕХНОЛОГИЙ КАК МЕТОДОЛОГИЧЕСКАЯ ОСНОВА ОПТИМИЗАЦИИ ГРАДОСТРОИТЕЛЬНЫХ РЕШЕНИЙ

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Аннотация. В статье рассматриваются возможности интеграции геоинформационных систем (ГИС) и технологий информационного моделирования зданий (BIM) для обоснования градостроительных решений. На основе анализа научных публикаций, цифровых инструментов и стандартов обмена данными предложена шестистадийная методика, объединяющая пространственный анализ территории, формирование проектных альтернатив, BIM-моделирование и многокритериальную оценку. Разработана система из шести групп критериев, включающая транспортно-пешеходную доступность, озеленение, соответствие параметров застройки, функциональную совместимость, инженерную и социальную обеспеченность. На условном примере показана логика расчета интегрального показателя и необходимость анализа чувствительности к весовым коэффициентам. Установлены методические преимущества и ограничения интеграции, связанные с совместимостью данных, точностью геопривязки и качеством исходной информации. Исследование носит теоретико-методологический характер и формирует основу для дальнейшей практической апробации на городской территории.

Ключевые слова: ГИС, BIM, градостроительное проектирование, пространственный анализ, интеграция данных, многокритериальная оценка, цифровое моделирование.

Введение

Современное градостроительное проектирование связано с необходимостью согласования большого числа факторов, определяющих качество и устойчивость городской среды. При выборе места размещения объекта или разработке планировочной структуры необходимо учитывать существующую застройку, транспортные связи, распределение населения, инженерную инфраструктуру, озеленение и установленные территориальные ограничения. Эти сведения создаются разными организациями, хранятся в различных форматах и нередко используются раздельно. В результате даже при наличии значительного объема исходных данных проектировщик не всегда получает целостное представление о территории и последствиях предлагаемых решений.

Традиционный градостроительный анализ основывается на изучении картографических материалов, текстовой документации, натурных обследованиях и сравнении графических вариантов. Данные методы сохраняют практическую значимость, однако ручное сопоставление разнородных материалов затрудняет своевременное

обновление информации, проверку пространственных взаимосвязей и оценку нескольких сценариев развития территории по единым критериям. Особенно заметными эти ограничения становятся в условиях сложившейся городской застройки, где изменение одного параметра может влиять на доступность общественных объектов, нагрузку на инженерные сети и состояние открытых пространств.

Перспективным направлением решения данной проблемы является интеграция геоинформационных систем (ГИС) и технологий информационного моделирования зданий (Building Information Modeling, BIM). ГИС обеспечивают анализ территории в ее географическом и функциональном контексте, тогда как BIM позволяет представить проектируемые здания и сооружения в виде структурированных информационных моделей. При совместном использовании эти технологии создают предпосылки для перехода от разрозненного анализа к согласованной системе обоснования градостроительных решений [2–4].

В предыдущем исследовании, посвященном алгоритмическому проектированию, рассматривались возможности климатически ориентированного формообразования на уровне отдельного архитектурного объекта [1]. Настоящая работа развивает общую проблематику цифровой оптимизации, но переносит акцент на территориальный масштаб, вопросы совместимости пространственных данных и процедуры выбора градостроительных альтернатив. Таким образом, предмет исследования не дублирует методы инсоляционного и ветрового анализа, представленные ранее.

Цель статьи — разработать и теоретически обосновать последовательность интеграции ГИС- и BIM-данных для комплексной оценки и выбора градостроительных решений на ранних стадиях проектирования. Для достижения цели рассматриваются аналитические возможности цифровых платформ, формулируются принципы организации единой информационной основы и предлагается система критериев многокритериального сравнения планировочных альтернатив.

Объектом исследования является процесс подготовки и обоснования градостроительных решений. Предмет исследования — методические принципы совместного использования геоинформационных и BIM-технологий при анализе территории и оценке альтернатив. Методологическую основу составляют анализ научной литературы и открытых технических стандартов, сопоставление функций программных средств, систематизация пространственных показателей и концептуальное моделирование процесса принятия решений. Исследование носит теоретико-методологический характер: реальные проектные данные не обрабатывались, а представленный ниже числовой пример предназначен исключительно для пояснения расчетной логики.

1. Цифровые инструменты градостроительного анализа

Геоинформационные системы предназначены для хранения, сопоставления, анализа и визуализации сведений, связанных с конкретными географическими координатами. В градостроительном проектировании их основное преимущество заключается не в создании цифровой карты как таковой, а в возможности рассматривать отдельные характеристики территории в виде взаимосвязанных тематических слоев. К таким слоям относятся границы участков, существующие здания, улично-дорожная сеть, остановки общественного транспорта, общественные учреждения, зеленые насаждения, инженерные коммуникации и зоны с особыми условиями использования.

QGIS относится к доступным геоинформационным платформам с открытым исходным кодом. Программа позволяет работать с векторными и растровыми данными, выполнять пространственные запросы, пересечения и буферизацию объектов, рассчитывать площади и расстояния, а также строить тематические карты. Для анализа доступности объектов могут использоваться инструменты сетевого анализа: определение кратчайших маршрутов и зон

обслуживания с учетом дорожной сети и заданной стоимости перемещения, например расстояния или времени [8]. Это принципиально отличается от простого построения окружности вокруг объекта, поскольку фактическая пешеходная доступность зависит от конфигурации улиц и наличия проходов.

ArcGIS Pro представляет собой комплексную среду пространственного анализа, в которой доступны инструменты обработки геоданных, трехмерной визуализации и оценки пригодности территорий для различных видов использования. В частности, метод взвешенного наложения тематических слоев (Weighted Overlay) позволяет привести неоднородные показатели к сопоставимой оценочной шкале и объединить их с учетом относительной значимости [9]. Для градостроительного исследования этот подход может быть применен при предварительном выявлении участков, отвечающих совокупности транспортных, экологических и функциональных требований.

В отличие от ГИС, BIM-среда прежде всего ориентирована на подробное представление зданий и сооружений. В Autodesk Revit информационная модель включает элементы с геометрическими и атрибутивными характеристиками: этажность, площади, объемы, категории помещений, параметры конструкций и другие сведения, необходимые для проектной координации. Данные параметры могут изменяться вместе с проектным решением, что позволяет использовать модель не только для выпуска чертежей, но и для проверки объемно-планировочных вариантов. Однако сами по себе сведения о здании не раскрывают его положение в системе городских связей, если не обеспечено сопоставление с территориальными данными.

Интеграция становится наиболее содержательной в тех случаях, когда данные из ГИС задают контекст и ограничения проектирования, а BIM позволяет уточнять параметры конкретных объектов. Например, ГИС-анализ может выявить участок с недостаточной обеспеченностью социальными учреждениями и приемлемой транспортной доступностью. Затем BIM-модель возможного общественного здания помогает оценить его размещение, ориентировочную вместимость, площадь застройки и взаимодействие с прилегающей территорией. Результаты уточнения возвращаются в пространственную модель и используются для повторной оценки района.

Для совместной работы важны не только функции программ, но и открытые форматы обмена. Стандарт Industry Foundation Classes (IFC), поддерживаемый buildingSMART и опубликованный в семействе ISO 16739, предназначен для структурированного обмена информацией об объектах строительства [6]. Стандарт CityGML, разрабатываемый Open Geospatial Consortium (OGC), описывает трехмерные городские объекты, их свойства и пространственные отношения [5]. Эти подходы дополняют друг друга, но не являются полностью взаимозаменяемыми: IFC ориентирован на подробную предметную структуру строительного объекта, тогда как CityGML — на геопространственный контекст и модели городской среды.

Научные исследования подчеркивают, что передача данных между BIM и ГИС сопровождается рисками потери геометрической детализации и смысловых характеристик объектов. В обзоре Y. Tan и соавторов систематизированы проблемы преобразования IFC в CityGML, связанные с различиями уровней детализации, геометрических представлений и семантики [2]. H.I. Senol и T. Gokgoz рассматривают преобразование IFC в CityJSON и отмечают значимость сохранения объектных связей при передаче информации [3]. Следовательно, интеграция требует не простого объединения моделей на одном экране, а заранее согласованных правил подготовки и проверки данных.

Таблица 1. Функциональная роль цифровых инструментов в предлагаемой методике

Инструмент / стандарт	Основные задачи	Роль в принятии решений
QGIS	Тематические карты, пространственные запросы, сетевой анализ	Выявление особенностей территории и расчет показателей доступности
ArcGIS Pro	Многослойный анализ, трехмерные сцены, оценка пригодности	Сопоставление пространственных альтернатив по набору критериев
Revit / BIM-среда	Информационная модель здания, площади, параметры объектов	Уточнение характеристик предлагаемых объектов и вариантов застройки
IFC / CityGML	Структурирование и передача объектных и геопространственных данных	Организация согласованного обмена сведениями между моделями

2. Методология интеграции ГИС и BIM

В рамках настоящего исследования предлагается поэтапная методика, объединяющая территориальный анализ, моделирование архитектурных объектов и оценку планировочных альтернатив. Ее исходный принцип заключается в том, что информация должна передаваться между стадиями не только в виде изображений и чертежей, но и как проверяемые цифровые данные с установленными источниками, координатами, датами обновления и значениями атрибутов. Такой подход согласуется с общей логикой управления информацией на протяжении жизненного цикла объектов, изложенной в ISO 19650-1:2018 [7].

Первый этап — постановка проектной задачи и определение границ анализа. До сбора данных необходимо уточнить, какое решение предстоит обосновать: размещение общественного здания, реконструкцию квартала, развитие жилой территории либо изменение функционального использования участка. Масштаб исследования задает степень детализации модели. Для городского района достаточно сведений об основных зданиях, улицах и объектах обслуживания, тогда как на уровне участка требуются точные границы, высотные отметки, параметры соседней застройки и инженерные ограничения.

Второй этап — формирование геоинформационной основы. В нее рекомендуется включать: кадастровые и планировочные границы; существующие здания с площадью застройки и этажностью; транспортные и пешеходные связи; остановки; общественные учреждения; озелененные территории; рельеф; сведения о сетях и планировочных ограничениях. Для каждого слоя фиксируются источник, дата получения, система координат, полнота и предполагаемая точность. При отсутствии достоверных сведений соответствующий показатель должен отмечаться как требующий уточнения, а не автоматически заменяться предположительным значением.

Третий этап — предварительный пространственный анализ. Средствами ГИС определяется структура землепользования, выявляются территориальные барьеры, рассчитываются доступные маршруты и локализуются зоны возможного конфликта функций. Результаты представляются в форме аналитических карт и таблиц, позволяющих формулировать проектные ограничения и потенциальные направления преобразования территории. На этой стадии исключаются варианты, противоречащие обязательным ограничениям: например, затрагивающие зоны, где размещение заданного объекта не

допускается. Юридическую и нормативную допустимость необходимо проверять по действующей документации и установленным процедурам, а не только по цифровой карте.

Четвертый этап — подготовка BIM-моделей перспективных объектов или укрупненных объемно-пространственных вариантов. Для ранней стадии целесообразно ограничиться характеристиками, действительно влияющими на градостроительный выбор: пятном застройки, высотой, этажностью, назначением, входными группами, связями с улицей, примерной вместимостью и потребностью в обслуживании. Избыточная проработка фасадов и внутренних элементов на данной стадии увеличивает трудоемкость, но не обязательно повышает достоверность территориального решения.

Пятый этап — согласование координатной и информационной структуры. Различия локальных проектных и географических координат могут приводить к смещению BIM-моделей относительно участка. Кроме того, при переносе объектов важно сохранять их устойчивые идентификаторы, назначения и количественные показатели. Проблема геопривязки BIM-моделей подробно рассматривается в исследовании P. Azari и соавторов [4]; прикладные инструкции по позиционированию CAD- и BIM-данных также представлены в документации ArcGIS Pro [10]. В рамках предлагаемой методики координатная проверка и контроль смыслового соответствия элементов рассматриваются как обязательные самостоятельные процедуры.

Шестой этап — расчет оценочных показателей и сравнение альтернатив. Полученные GIS- и BIM-данные сводятся в единую таблицу критериев. Каждый вариант должен анализироваться по одинаковым правилам, в одном территориальном контуре и при сопоставимом уровне детализации. После сравнения возможна корректировка расположения и параметров объекта с последующим повторным расчетом. Итерационность обеспечивает связь между территориальными ограничениями и архитектурным решением, не превращая цифровую систему в автономный механизм выбора.

Важное место занимает управление изменениями. Если в проекте уточняется этажность здания, меняется схема проезда или обновляется слой инженерных сетей, это должно отражаться в соответствующих расчетах и документации. Для контроля рекомендуются единые идентификаторы объектов, журнал версий, перечень обязательных атрибутов и распределение ответственности за обновление данных. Методика не предполагает, что все программные продукты обязаны работать в одной базе: принципиальным является воспроизводимый обмен согласованной информацией.

Рисунок 1. Предлагаемая последовательность интегрированного цифрового анализа



Примечание: разработано в рамках настоящего исследования.

Предложенная последовательность может применяться как в рамках одной проектной организации, так и при взаимодействии градостроителей, архитекторов и специалистов по инженерной инфраструктуре. При этом качество результата зависит не от количества подключенных программных продуктов, а от полноты исходной информации, правильности постановки задачи и согласованности используемых критериев.

3. Многокритериальная оценка градостроительных решений

Градостроительные решения редко могут быть обоснованы одним показателем. Вариант, обеспечивающий высокую интенсивность использования территории, не обязательно является оптимальным с точки зрения доступности зеленых зон, нагрузки на инженерные сети или удобства повседневных перемещений. Поэтому предлагается использовать систему взаимосвязанных критериев, объединяющих пространственные, функциональные и инфраструктурные характеристики.

Первая группа показателей характеризует транспортно-пешеходную доступность. Здесь рассматриваются время или протяженность фактического маршрута до остановок общественного транспорта и повседневных объектов обслуживания, связность уличной сети и наличие пешеходных барьеров. Расчет рекомендуется проводить по сети доступных проходов с учетом направлений движения и ограничений, а не исключительно по прямолинейным расстояниям [8].

Вторая группа относится к озеленению и открытым пространствам. Для полноценной оценки следует учитывать не только долю зеленых территорий, но и их фактическую доступность, непрерывность пешеходных маршрутов, характер благоустройства и возможности повседневного использования. Значительная площадь озеленения за границей доступного маршрута не равнозначна небольшому, но хорошо связанному общественному пространству внутри жилой территории.

Третья группа описывает соответствие параметров застройки планировочной задаче. В нее могут входить плотность застройки, этажность, площадь застроенной поверхности, распределение открытых участков и соотношение функциональных зон. Важно, что

максимальное значение плотности само по себе не рассматривается как положительный результат: оценивается соответствие выбранного решения целевым характеристикам территории, ее инфраструктурной емкости и установленным ограничениям.

Четвертая группа раскрывает функциональную совместимость. Речь идет о согласованности размещаемых функций с существующим окружением, наличии удобных связей между жильем, рабочими местами, общественными объектами и рекреационными пространствами, а также предотвращении конфликтов между видами использования территории. Пятая группа отражает предварительную обеспеченность инженерной инфраструктурой и возможность подключения новых объектов. Шестая группа характеризует доступность социальной инфраструктуры, включая учреждения образования, здравоохранения и повседневного обслуживания.

Таблица 2. Предлагаемая система критериев оценки градостроительных альтернатив

Критерий	Возможный показатель	Источник данных
Транспортно-пешеходная доступность	Время маршрута до остановок и ключевых объектов; связность сети	Улично-дорожная сеть, проходы, остановки, ГИС
Озеленение и открытые пространства	Доступная площадь и связность зеленых территорий	Слои зеленых насаждений, общественных пространств
Соответствие параметров застройки	Этажность, плотность и площадь застройки относительно целевого режима	Планировочные документы, BIM-параметры
Функциональная совместимость	Соответствие назначения объекта окружающему землепользованию	Функциональное зонирование, ГИС
Инженерная обеспеченность	Наличие точек подключения и предварительная оценка допустимой нагрузки	Сведения владельцев сетей, инженерные разделы проекта
Доступность социальной инфраструктуры	Маршрутная доступность учреждений с учетом их фактической мощности	Адресные данные учреждений, ГИС

Для аналитического сравнения значения показателей требуется перевести в общую шкалу, поскольку исходные единицы измерения различаются. В простейшем случае используется шкала от 1 до 5, где 1 означает наименее благоприятное, а 5 — наиболее благоприятное состояние по конкретному критерию. Правила присвоения оценок устанавливаются до сравнения вариантов и должны одинаково применяться ко всем альтернативам. При наличии достаточных количественных данных возможно нормирование по установленным порогам либо относительно целевого диапазона. При этом обязательные градостроительные ограничения не следует заменять низким баллом: недопустимые варианты должны исключаться до итогового ранжирования.

Для сводной оценки предлагается аддитивная модель: $I_j = \Sigma (w_i \times s_{ij})$, где I_j — итоговая оценка j-го варианта, w_i — вес i-го критерия (сумма весов равна 1), s_{ij} — нормированная оценка варианта j по критерию i. Модель удобна для первоначального сравнения, однако предполагает частичную компенсируемость критериев: высокие баллы по одному показателю могут перекрывать низкие значения другого. Поэтому индекс должен дополняться проверкой критических ограничений и анализом отдельных показателей [9].

Весовые коэффициенты определяются в соответствии с целями проекта. Их можно получить экспертным согласованием, с участием заинтересованных сторон или через формализованные методы принятия решений. Важным условием является прозрачность процедуры: автор исследования должен указать, почему отдельные критерии признаны более значимыми, какие сведения использовались и каким образом изменение весов влияет на итоговый выбор. Поскольку универсального распределения весов для всех территорий не существует, в каждом проекте значения следует уточнять применительно к местным условиям.

Наконец, при оценке необходимо различать показатели, достоверно рассчитываемые средствами, ГИС и BIM, и характеристики, требующие дополнительных обследований. Например, потенциальное размещение объекта вблизи инженерной сети не доказывает наличия свободной пропускной способности. Аналогично, картографическая близость школы не подтверждает наличие мест для новых жителей. Такие сведения проверяются у ответственных организаций, а при их отсутствии отражаются как ограничения достоверности исследования.

4. Результаты и обсуждение

Основным результатом настоящей работы является концептуальная схема согласованного использования ГИС и BIM на ранних стадиях градостроительного проектирования. В отличие от подхода, при котором карта территории и модель здания создаются независимо друг от друга, предложенная схема устанавливает последовательность переходов между пространственными данными, проектными параметрами и оценочными показателями. Это позволяет сделать основания выбора решения более явными и пригодными для повторной проверки при корректировке проекта.

Для демонстрации работы многокритериальной модели рассмотрен условный пример сравнения трех сценариев развития городской территории. Сценарий А ориентирован на более интенсивную застройку и усиление транспортной доступности; сценарий Б предполагает сбалансированное развитие объектов и общественных пространств; сценарий В отдает приоритет озеленению и функциональному разнообразию. Данный пример является учебно-методической иллюстрацией. Приведенные оценки не получены в результате расчетов для реального участка, не являются нормативными величинами и не предназначены для обоснования конкретного проекта.

Таблица 3. Иллюстративная матрица многокритериального сравнения трех сценариев

Критерий	Вес, доля	А	Б	В
Транспортная доступность	0,25	5	4	3
Доступность озеленения	0,20	2	4	5
Параметры застройки	0,20	5	4	3
Совместимость функций	0,15	3	4	5
Инженерная обеспеченность	0,10	4	4	3
Социальная инфраструктура	0,10	3	4	4
Итоговый индекс I_j	**1,00**	**3,80**	**4,00**	**3,80**

При выбранных условных весах сценарий Б получает итоговую оценку 4,00 балла, а сценарии А и В — по 3,80 балла. Данное соотношение не свидетельствует о доказанном превосходстве определенного градостроительного решения: оно лишь показывает, каким образом принятая система приоритетов влияет на ранжирование вариантов. Если для рассматриваемой территории более значимым окажется, например, сохранение зеленых пространств, увеличение веса соответствующего критерия может изменить порядок предпочтения сценариев. Поэтому выбор следует сопровождать анализом

чувствительности, в котором веса последовательно изменяются в заранее оговоренном диапазоне.

В реальном проекте каждый балл должен опираться на наблюдаемый показатель и утвержденное правило преобразования. Так, оценку доступности можно получить из расчета пешеходных маршрутов, показатель застройки — из площади участка и BIM-геометрии, а долю озеленения — из проверенного пространственного слоя. По результатам корректировки выбранной альтернативы повторно рассчитываются значения критериев, что делает процесс обоснования решений прослеживаемым.

Предлагаемый подход имеет несколько потенциальных преимуществ. Во-первых, он помогает выявлять противоречия между территориальными и объектными параметрами до углубленной архитектурной проработки. Во-вторых, обеспечивает единый набор критериев для сопоставления альтернатив, уменьшая зависимость обсуждения от разрозненных графических материалов. В-третьих, создает возможность обновлять отдельные данные и повторять оценку, не начиная весь анализ заново. Вместе с тем перечисленные преимущества представляют собой методологически обоснованные ожидания; для доказательства сокращения трудозатрат или повышения качества решений необходима отдельная практическая апробация.

Среди ограничений интеграции особое значение имеют несовпадение систем координат, различия в степени детализации моделей, потери атрибутивных данных при конвертации и отсутствие единых правил именования объектов. Указанные проблемы отражены в современных исследованиях взаимосвязи IFC, CityGML и GIS [2–4]. Дополнительные трудности связаны с неполнотой муниципальных и инженерных данных, организационными ограничениями доступа, необходимостью обучения специалистов и различиями в информационных требованиях участников проекта. Даже технически корректная совмещенная модель не обеспечивает достоверного результата, если исходные сведения устарели или противоречат друг другу.

Отдельного обсуждения требует роль проектировщика. Многокритериальный индекс не способен полностью описать историко-культурные, социальные и композиционные особенности городской среды. Некоторые качества требуют экспертной интерпретации. Поэтому цифровые средства целесообразно рассматривать как систему поддержки решений: они структурируют информацию и помогают аргументировать проектную позицию, но окончательный выбор остается за специалистами и принимается с учетом действующих норм и общественных интересов.

Перспективы дальнейших исследований связаны с апробацией методики на конкретной городской территории, сопоставлением цифрового и традиционного анализа, проверкой устойчивости весовых коэффициентов и формированием регламента обмена данными. Практический эксперимент должен включать геопривязанные исходные данные, документированные правила расчета, сопоставимые альтернативы и независимую проверку ключевых показателей. Это позволит оценивать точность, воспроизводимость и трудоемкость процесса проектирования.

Заключение

Проведенное теоретико-методологическое исследование показывает, что интеграцию ГИС и BIM целесообразно рассматривать не как механическое объединение двух типов программ, а как организацию последовательного обмена пространственными, объектными и оценочными данными. ГИС позволяют выявлять особенности городской территории и рассчитывать показатели ее функционирования, тогда как BIM уточняет параметры рассматриваемых архитектурных объектов и формирует информационную основу для проверки проектных альтернатив.

В качестве основного результата предложена шестистадийная методика, включающая постановку задачи, формирование геоинформационной основы, пространственный анализ, подготовку BIM-вариантов, согласование данных и многокритериальное сравнение решений. Сформулирована система из шести групп критериев, охватывающая транспортно-пешеходную доступность, озеленение, параметры застройки, функциональную совместимость, инженерную и социальную обеспеченность.

Условный пример расчета показал логику сопоставления альтернатив при заданных весах, одновременно продемонстрировав зависимость итоговой оценки от выбранных приоритетов. Он не заменяет натурных обследований и расчетов для конкретного проекта. Обязательные ограничения должны проверяться отдельно от интегрального индекса, а качество выводов определяется полнотой, актуальностью и проверяемостью исходной информации.

Таким образом, предложенный подход может служить методической основой для дальнейшей разработки цифровых процессов в архитектурном и градостроительном проектировании. Его практическая ценность заключается в возможности сделать выбор пространственных решений более прозрачным, последовательным и воспроизводимым. Следующим этапом исследования должна стать апробация методики на реальной территории с использованием сопоставимых ГИС- и BIM-данных и последующей оценкой результатов.

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THE DIALECTICS OF INTERACTION OF ARCHITECTURAL FORMS OF VARIOUS TERRITORIAL AND TEMPORAL ORIGIN

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1 Introduction

Any phenomenon with a specific name a priori implies a degree of uniqueness, allowing it to be identified by that name. Moreover, when it comes to culturally and geographically specific phenomena, this uniqueness encompasses, to varying degrees, most processes, including, of course, the formation of forms for life processes. Accordingly, interest arises in specifying the components of this uniqueness, and the administrative-territorial concept of "region" in the context of architecture acquires a specificity based on the factors that shape this type of cultural materialization.

The phenomenon of organizing space for life based on a complex of factors related to natural and climatic conditions, the specifics of economic activity, the way of life and worldview of residents, the administrative and political structure of the country, and the availability of local and imported building materials. Moreover, each of these factors, taken separately, can serve as the basis for grouping examples for analysis. However, only in combination with historical-territorial specification does the combination of these factors, which have their own hierarchy of significance in different periods of their existence, allow us to begin searching for distinctive features (including architectural and artistic forms) in the complexly structured system of architectural regions and subregions. Various aspects of the problem have been analyzed in the works of I.A.Azizyan, A.V.Ikonnikov, A.V.Ryabushin, K.I.Samoilov, K.Frampton, V.L.Khait, S.O.Khan-Magomedov, and others [1-8].

2 Methods

The research method employed is a general scientific dialectical approach to cognition, from observation through generalization to practice. The following were applied:

- an integral-differential approach, which allows for the division of a body of architectural and artistic forms into a multitude of themes characteristic of each period based on their similarity, and for their unification into areas reflecting the specific characteristics of one or more stages;
- a formal approach, which allows for the tracing of the development of various architectural and artistic forms;
- an iconographic approach, which allows for the exploration of the manifestation of features of various prototypes in architectural and artistic forms;
- a structural-semiotic approach, which allows for the modeling of the development of architectural and artistic forms.

3 Materials

One of the characteristic features of the modern understanding of the development of artistic forms is their consideration not in an isolated, "easel" form, but from the perspective of their utilitarian, historical, cultural, and specific environmental determinacy. This implies an

increased importance of factors involved in analysis, relating to a number of initial functional aspects, the spatially organizing role of a given work, and the processes of form-generation itself, which collectively determine a number of parameters of syntheticity.

Equally important is the consideration of the processes by which the architectural and artistic forms of a work adapt to varying degrees of change in the building's function and spatiotemporal context. This implies the methodological importance of examining the history of the creation of the analyzed form and the processes of its physical and semantic transformation as it undergoes active use. In this regard, museification can be considered a sort of final stage, isolating the architectural and artistic form from its spatial and semantic context for passive use without the physical modifications conventionally excluded by periodic restorations.

Of particular importance in such an interpretation is the a priori universality, within certain limits, of a number of architectural and artistic forms and of the work as a whole, opening up the possibility of a very broad range of its exploitation (adaptations) both physically and semantically. Indicative here is the possibility of conducting a retrospective analysis, emphasizing the stages of natural-historical "loss of knowledge" or its deliberate concealment, which subsequently lead to a dramatic shift in the utilitarian-semantic interpretation of form. Equally interesting in this context are periods of "restoration of historical memory," returning a form either to its original form or to one of its historically emerged or intentionally imposed definitions, depending on the ideological commitment of the stage that included it in active exploitation. A.V.Ryabushin notes: "Although the semantic content of architectural images is fluid and their content is reinterpreted over time, one cannot, however, discount the author's initial assumptions and ideological positions – for whom and why they created, what exactly they created. This primary authorial position practically forever colors the imagery of architecture, despite all its dynamics and historical reinterpretations" [3, p. 311].

A significant aspect is also the inherent difficulty in attributing artistic forms by type from spatial-parametric and operational-semantic perspectives. For each time, it is necessary to establish difficult-to-justify criteria for isolating a particular element from an essentially synthetic work.

And although it is, in principle, possible to distinguish periods of "syntheticism" and "easelization" of forms, such a distinction is highly arbitrary, as it pertains more to the particularities of the era's worldview and self-assessment, while the role of "evolved" forms is occupied by appropriately interpreted "pure" forms. At the same time, there is a desire to solve the entire complex of problems either in isolation within the framework of a "budding" form or proto-forms purified of "accidental" accretions, or, conversely, to model new types of unity at the level of creating integral architectural and artistic forms. I.A.Azizyan writes: "Architecture interacts with all, and not just the spatial, arts of its era, assimilating the leading ideas and figurative concepts crystallized in other arts." In turn, certain features of artistic consciousness, which have received their most vivid embodiment in architecture, spread under its influence to other forms of art within the integrity of the historical and cultural era" [1, p. 11].

Viewing architectural and artistic forms from such perspectives proves highly productive under certain conditions, as emphasizing the subjective approach to the process is also important. This, in turn, determines the definition of architectural and artistic forms from the perspective of eras and their corresponding application: as revered rarities in religious or museum memorials; as elements actively used "for their intended purpose"; as adaptations consciously or spontaneously reinterpreted relative to their original function or meaning; as elements spontaneously or deliberately dismembered through natural or artificial destruction. Such processes are very clearly manifested in the spatial and semantic transformations of architectural and artistic forms and the works themselves as a whole upon a change of ownership, in the transfer of elements to spatial

and semantic contexts of different significance, in the restoration or reconstruction of artifacts from past eras significant to the current period, and in much more.

Architectural-regional-temporal differentiation implies the presence of components adequate to the specifics of a particular type, which, when fixing time frames, leads to the need to define archetypes for a given region.

The classification of an architectural and artistic form as "local" is based, firstly, on its specificity to a given area, and secondly, on established parameters. However, these criteria are somewhat meaningless without a time specification, since each form has its own period of origin, and any introduced form, after regional assimilation over a given period, provided there is a sufficient time gap for subsequent periods, can also be classified as local. As S.O.Khan-Magomedov notes, "every innovation transforms over time into a more or less stable tradition, and every tradition begins its existence as an innovation" [8, p. 18]. Another important aspect of local forms is that their areas are often not limited by administrative-territorial boundaries, since the latter are historically significantly more dynamic than some architectural formations. Over the course of their existence, local architectural and artistic forms evolve to one degree or another.

The phenomenology of other-regional architectural and artistic forms is directly linked to processes of ethnic interaction based on natural or artificially stimulated population migration within varying quantitative limits. Differentiating the term "other-regional" with respect to a specific group of components of the general concept of "architectural form" represents the process of identifying a specific accentuation of architectural form-creation ideas by migrants or local residents imbued, for various reasons, with their worldview in a situation initially unsuitable for the expression of these ideas. Moreover, this applies to most of the basic or derived parameters of regional distinctiveness. A difference in even one parameter, which, in principle, allows for the discussion of at least sub-regional characteristics, accordingly allows for the classification of a form as other-regional.

A complex system of mutual assumptions permeates the distinction between a other-regional form and a local one, for in a number of cases, only the relative historical proximity of the emergence of a given model in a given territory precludes its being considered local. And for some forms clearly classified as "local," the possibility of retrospective analysis revealing the adaptive transformations of the initially foreign inclusion is quite obvious. The existence of other-regional forms in an environment different from that which gave rise to them is impossible without some degree of adaptive transformation of both individual elements and the structure as a whole.

Trans-regional architectural and artistic forms, not directly linked to population migration, are attributed to the architectural universals of a particular time and, depending on the diverse orientation of the comparative self-assessment of local culture, have varying degrees of prevalence in each period. The totality of trans-regional architectural forms overlaps to some extent with the sphere of non-regional forms. This raises the problem of temporal separation and the definition of archetypes. The dilemma of direct and indirect borrowing of form-creating ideas also has a certain degree of conventionality. However, the most important criterion for attributing an architectural form as "trans-regional" is its immutability or very slight transformation when manifested in different regional conditions.

The evolution of local architectural forms, the adaptation of other-regional ones, and the emergence of trans-regional ones collectively define a process of interaction that generates uniquely transformed patterns. Coexisting within a single regional cultural space, forms of diverse origins gradually begin to synthesize. At the same time, techniques characteristic of forms of one origin enrich the palette of forms of another. This diffusion is observed in different periods and manifests itself with varying degrees of intensity. Initially, the other-regional form manifests itself in its "pure form," and only after a certain period of time do its individual elements, on the one

hand, begin to be replaced by elements of local forms, while, on the other hand, elements of non-regional innovation appear within local forms.

A similar interpretation seems possible in the sphere of definitions of specific, time-specific architectural and artistic forms.

The definition of an architectural and artistic form as "contemporary" implies, along with the presence of established parameters, its specificity to a given period of time. Here, the temporal specification of its origin is also essential, for the totality of modern forms includes not only "momentary" innovations, but also a number of other-time forms. After a specific-temporal adaptation over a given period, given a sufficient time gap from the period of origin for a given period, these forms also acquire the quality of contemporary: historicism, according to A.V.Ikonnikov, manifests itself not as "the name of a specific direction in the practice of a certain time, but a tendency that runs through all periods of architectural development," which "is determined by an appeal to the culture of the past (as a rule, one with which its time no longer maintains direct continuity) to solve the problems of the present" [2, p. 7]. In the context of emerging contemporary forms, it's also important to note that periods of their active use are sometimes not limited to socio-historically significant time periods. Despite the transformation of the underlying system or its transfer to another, a multifaceted rethinking of their characteristics allows these forms to be perceived as contemporary in the context of a new cultural phenomenon. Throughout their existence, modern architectural and artistic forms evolve to varying degrees.

The emergence of otherworldly architectural and artistic forms is directly linked to both the processes of rethinking modernity in the context of history or place in culture, and to the processes of population migration, which to a certain extent stimulate this rethinking. The differentiation of the term "otherworldly" in relation to a certain group of components of the general concept of "architectural form" represents the process of identifying a kind of accentuation of historically established ideas of architectural form-making by migrants or local residents in a situation that is initially unnecessary for the manifestation of these ideas. Moreover, each of the attracted forms implies its own degree of justification for application and the active promotion of its use. Thus, for a number of modern cultures, as V.L.Khait notes, "the next appeal to the classics does not require explanations and justifications, whereas the revival of regional historical architecture and, especially, the birth of new figurative structures always requires targeted declarations in verbal form, accompanied by the advancement of ideological and artistic [...] professional concepts" [6, p. 164].

A complex system of mutual assumptions permeates the difference between a form of another time and a modern one, since in a number of cases only the relative historical proximity of the appearance of a particular example in the totality of architectural forms of a period prevents it from being considered modern. Analyzing the specifics of the process, S.O.Khan-Magomedov writes: “The old can be the basis for the creation of a new style when it is perceived by contemporaries as new, when what it replaces seems outdated, moribund. The reasons for turning to the past when creating a new style can be very diverse – social, national, purely professional. But under all conditions, an artistic novelty in the perception of old forms is necessary. A certain time gap, a change of generations is required for the revived old to be perceived freshly and in a new way. The proximity in time to the legacy of the past, which is being reintroduced into life, forces us to perceive it as a restoration of the past, as conservatism” [8, p. 30]. It's significant here that for some forms clearly classified as "modern," the possibility of retrospective analysis is quite evident, revealing adaptive transformations of an initially other-time inclusion. The existence of other-time forms in a spatio-temporal continuum distinct from the one that gave rise to them is impossible without some degree of adaptive transformation of both individual elements and the structure as a whole.

Transtemporal architectural and artistic forms, not directly linked to generational change or population migration, are identified within the realm of architectural universals of a particular time and, depending on the diverse vectors of comparative self-assessment of contemporary culture, have varying degrees of prevalence in each period. The totality of transtemporal architectural forms overlaps to some extent with the realm of other-time forms. Here, the problem of temporal separation and the definition of a kind of proto-time also arises. The dilemma of direct and indirect borrowing of form-creating ideas also has a certain degree of conventionality. However, the most important criterion for classifying an architectural form as "transtemporal" is its immutability or very slight transformation when manifested in different historical conditions.

The emergence of contemporary architectural forms, the adaptation of other-time forms, and the emergence of trans-temporal forms collectively define a process of interaction that generates uniquely transformed patterns. Coexisting within a single regional cultural space, forms of diverse origins gradually begin to synthesize. At the same time, techniques characteristic of forms of one origin enrich the palette of forms of another. This diffusion is observed in different periods and manifests itself with varying degrees of intensity. Initially, the other-time form manifests itself in its "pure form", and only after a certain period of time do its individual elements, on the one hand, begin to be replaced by elements of modern forms, while, on the other hand, elements of other-time innovation appear within modern forms.

4 Results and Conclusion

The process of natural lag in the "unique-mass" and "center-periphery" systems clearly reflects the evolution of architectural and artistic forms, and periods of transition acquire importance in terms of the creative direction of architectural activity. Moreover, there is not only a change in the types of "unique" examples of imitation and themes of interpretation, but also a shift, rearrangement, or replacement of "centers" with a corresponding reorientation of the vectors of innovation dissemination. Architectural and artistic forms, depending on a range of factors, are used in various combinations. Their entire diversity, implying not only the uniqueness of individual sets of components but also nuanced intra-formal differences, constitutes a totality that, with a certain degree of conventionality, can be structured in one way or another. The interpenetration of form-making techniques, combined with the reflection of period-specific cultural foundations, gives rise to the phenomenon of a specific architectural and artistic form, possessing, regardless of its origin, an original appearance unique to a given region and time. These forms, having undergone historical selection, can evolve into local and contemporary forms for the subsequent period, evolving depending on its particular characteristics in one aspect or another within the context of a new wave of other-(trans)regional and other-(trans)temporal inclusions. The emergence and development of such forms gives rise to an architecture clearly classified as "specific-temporal regional."

Evolving local and contemporary, adapting other-regional and other-temporal, as well as emerging trans-regional and trans-temporal architectural and artistic forms, interacting to generate specific-temporal regional phenomena, coexist in a specific manner throughout individual periods.

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Journalism

Ethical Governance of Artificial Intelligence Across the News Lifecycle

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Abstract
Artificial intelligence now supports or shapes news gathering, verification, production, ranking, translation, and audience engagement. These uses can expand reporting capacity, but they also redistribute editorial power and create risks involving privacy, discrimination, false or synthetic evidence, opaque decisions, worker autonomy, and unequal access to reliable news. This conceptual article develops a risk-proportionate framework for newsroom governance by connecting journalism ethics with the principles visible in the Global MOOC on the Ethics of AI and with international guidance and recent research. It argues that ethical performance depends less on a generic label for AI than on the task, data, degree of editorial influence, affected people, and remedies available when harm occurs. The proposed approach requires a public-interest purpose, data and rights review, task-level risk controls, meaningful human editorial authority, context-sensitive disclosure, and continuous monitoring with correction and appeal. Three original figures translate these principles into a news-lifecycle map, a task-risk guide, and an accountability loop. The central conclusion is that newsroom AI should be governed as editorial infrastructure: its use must remain answerable to professional judgment, pluralism, human rights, and the public's ability to question and correct journalism.
Keywords: artificial intelligence; journalism ethics; newsroom governance; transparency; accountability; fairness; editorial responsibility

1. Introduction

Artificial intelligence is no longer confined to experimental newsroom projects. Automated transcription, translation, data analysis, search, summarization, headline drafting, image generation, and personalized distribution can all enter ordinary editorial workflows. A single newsroom may use several tools built by external providers, each with different data practices and different levels of influence over what is reported, how it is framed, and who sees it. This makes AI ethics a question about institutional choices as much as about model outputs.

Pattern recognition can help reporters examine large document collections; speech tools can make interviews searchable; translation can widen access to sources; and repetitive production tasks can be completed faster. Yet efficiency is not equivalent to public benefit. A system that saves time may also expose confidential material, reproduce stereotypes, fabricate plausible details, narrow the range of voices in a story, or make an editor dependent on a vendor whose design and data practices are difficult to inspect. The Council of Europe therefore treats adoption itself as an editorial decision and calls for mission alignment, risk assessment, accountable ownership, and ongoing review (Council of Europe, 2024).

Journalism has longstanding duties of accuracy, independence, fairness, privacy protection, and accountability. AI does not remove those duties; it complicates how they are fulfilled. A newsroom cannot delegate responsibility to a model, a vendor, or a disclosure label. It must be able to explain what the system did, who reviewed its contribution, what evidence supports the published claim, and how affected people can seek correction.

This article makes a practical argument: ethical AI journalism requires governance across the whole news lifecycle, with controls proportionate to the stakes of each task. The decisive unit is not the technology category but the editorial function. A language model used to normalize punctuation presents a different risk from one used to identify a confidential source, rank political news, or create a realistic image of an event. The paper first links course principles to journalism's public role, then reviews risks across reporting, production, distribution, and work, and finally proposes an implementable governance framework.

2. Ethical foundations and analytical scope

The course outline for the Global MOOC on the Ethics of AI presents a useful set of connected principles: safety and security; fairness, non-discrimination, and inclusion; privacy and data governance; transparency, explainability, and accountability; environmental sustainability; proportionality and avoiding harm; and human autonomy and meaningful work (UNESCO, n.d.). These ideas can be translated into journalism without treating the newsroom as an ordinary technology user. News organizations exercise editorial power, handle sensitive sources, distribute public information, and help shape the conditions for democratic debate.

UNESCO's Recommendation on the Ethics of Artificial Intelligence gives this translation a rights-based foundation. It links human dignity and human rights with fairness, transparency, accountability, privacy, diversity, environmental stewardship, and the impact of AI on labour and communication (UNESCO, 2021). In journalism, these values apply both to internal AI use and to reporting about AI. The first concerns how the newsroom gathers, creates, and distributes news; the second concerns whether journalism independently examines the power, benefits, and harms of AI systems in society. UNESCO's handbook for journalism educators stresses the second role: coverage should explain AI's wider social effects, including unequal benefits and human-rights risks, rather than simply repeat product claims (Jaakkola, 2023).

Sector-specific guidance adds institutional detail. The Council of Europe places the decision to implement AI within a newsroom's editorial mission and recommends systematic, participatory risk assessment, responsible procurement, and regular monitoring. It also distinguishes repetitive tasks from work requiring expert judgment, creativity, or discretion, which calls for stronger human oversight (Council of Europe, 2024). Research on AI ethics in journalism likewise finds that principles are easier to publish than to embed in system design and daily practice; their enforcement remains under-studied (Porlezza & Schapals, 2024).

3. Method and conceptual approach

This is an integrative conceptual analysis, not a systematic review, newsroom audit, or empirical experiment. It brings together peer-reviewed research, international guidance, and the course principles described above to identify recurring ethical pressure points and convert them into operational controls. Sources were selected for direct relevance to journalism, AI governance, or the social conditions under which AI-supported news is produced and received. The article makes no claim that the selected sources exhaust the field.

The three figures are original conceptual syntheses. They organize principles and proposed controls; they do not display measurements, survey results, or estimated effect sizes. The framework is intended as a decision aid for editors, reporters, product teams, and small newsrooms that need practical rules before adopting a tool.

4. Ethical pressure points across the news lifecycle

AI can enter journalism before an article is drafted and after publication. A lifecycle view prevents policy from focusing only on generated text while ignoring procurement, source handling, story selection, recommendation, and response to audience complaints. Figure 1 maps these stages to safeguards that should remain visible throughout the process.

4.1 Newsgathering and data stewardship

AI-assisted search, transcription, translation, face or object detection, and document analysis may help reporters find leads in large collections. The same functions can expose people who never agreed to be profiled, transform public information into sensitive inference, or send confidential material to an external service. A source's name, voice recording, location, or unpublished documents can create harm even when the final story does not reveal them. Privacy review must therefore cover the input, the provider's retention and reuse terms, access controls, and what happens to material after the task is complete.

Data quality also shapes representation. News archives may overrepresent powerful institutions and speakers who were historically treated as authoritative. A system trained on or prompted with such material can make that imbalance appear natural. Reporters should record where a dataset came from, which populations are missing, and whether a result can be independently checked. A model's confident answer is a lead for verification, not a source.

4.2 Production, verification, and representation

Generative tools can draft summaries, headlines, captions, and translations, but fluent language can conceal unsupported claims. A newsroom's verification standard must apply to each factual proposition, quotation, image, and attribution, not merely to the text as a whole. Editors should distinguish facts supported by documents or interviews from assertions generated from a model's learned patterns. When the system cannot show provenance, its output should not be treated as evidence.

Bias can arise from training data, prompt design, output filters, or the choice of what to summarize. Research comparing several generative systems on journalism-related content makes clear that representational bias is a tool-specific issue that can be examined rather than assumed away (Castillo-Campos et al., 2024). Reviewers should ask whose perspective is foregrounded, whose is omitted, whether a translation changes tone or uncertainty, and whether a description relies on stereotypes. A human check is meaningful only if the reviewer has time, subject knowledge, access to original evidence, and authority to reject the output.

Disclosure should follow the role AI played. A spelling correction that leaves meaning unchanged may not warrant a public label. AI-created imagery, synthetic audio, substantial drafting, or automated selection that materially affects a story's meaning or visibility ordinarily calls for clear, specific disclosure. A generic badge is insufficient when readers need to know whether AI generated, edited, translated, or ranked content. Newsroom policies increasingly emphasize human oversight, verification, transparency, and data or copyright protection, although written rules alone do not demonstrate consistent implementation (Sánchez-García et al., 2025).

4.3 Distribution, recommendation, and pluralism

Recommendation systems decide which journalism becomes visible and to whom. Their ranking criteria may optimize clicks, time spent, subscription conversion, or predicted relevance. Those goals can conflict with editorial commitments to civic importance, geographic coverage, viewpoint diversity, and access to unfamiliar subjects. A system can be accurate at predicting individual engagement while narrowing the public's shared field of attention. Its ethical performance should therefore be reviewed at both the individual and population levels.

Fairness in this setting is not a single statistical score. Editors need to examine whether groups and regions receive comparable opportunities for coverage, whether certain topics are systematically downranked, and whether readers can understand or adjust personalization. Studies of public attitudes toward AI in news also find that perceptions vary with institutional trust, media trust, and political attitudes; audiences should not be treated as a uniform group that will respond to one disclosure formula (Araujo et al., 2023).

A newsroom audit can compare the stories a recommender displays with the stories editors consider important, then ask which subjects, communities, and locations lose visibility. Metrics should be reviewed alongside editorial judgment because an engagement measure can reward familiarity and emotional intensity while overlooking public value. Readers should be able to reset or broaden recommendations, and editors should retain a way to surface urgent or underrepresented coverage. These safeguards make personalization compatible with editorial pluralism rather than allowing a platform metric to define it.

4.4 Work, sustainability, and institutional dependence

Automation can reduce repetitive work, but it can also compress staffing, weaken apprenticeship, and transfer skilled tasks to systems whose failure modes journalists cannot inspect. Interviews with journalists suggest that professionals respond by redefining expertise around human judgment, contextual knowledge, and other forms of craft that are difficult to reduce to text production (Møller et al., 2025). Responsible adoption should include workers in decisions, specify which roles change, provide training, and monitor whether productivity gains are accompanied by reduced editorial capacity.

Access to tools and technical expertise is uneven. Small, local, and less-resourced newsrooms may face pressure to adopt systems without the procurement, testing, or legal support available to large publishers. Research on the global AI gap in journalism cautions that calling this a lag to be closed can obscure structural differences and the question of whose model of progress is being promoted (Schaetz & Schjøtt, 2026). Vendor dependence can also create lock-in, limit audit access, and shift bargaining power away from news organizations. Environmental costs, licensing terms, copyright, and the effect on freelancers and creative workers belong in the same assessment.

A responsible business case should identify who benefits from saved time and who bears the transition costs. If automation removes routine work, managers should consider how junior journalists will learn source evaluation, editing, and data skills. Training should include the limits of tools, privacy practices, verification, and the ability to challenge a system's recommendation. Newsrooms should also consider the energy and infrastructure demands of repeated model use and prefer a smaller or simpler system when it meets the editorial need.

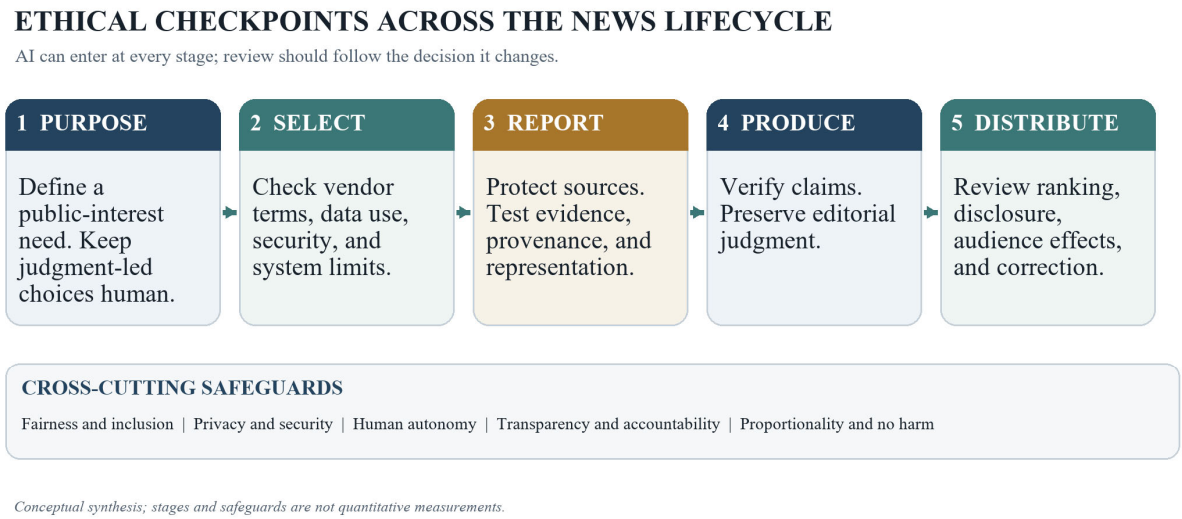


Figure 1. Ethical checkpoints across the news lifecycle. Conceptual synthesis informed by the course outline, UNESCO (2021), and Council of Europe (2024).

5. A risk-proportionate governance framework

A workable policy should be short enough for routine use and strong enough to govern high-stakes cases. The framework proposed here has six controls: establish a public-interest

purpose; classify risk by task and context; preserve accountable human judgment; protect data and test fairness; disclose material involvement; and monitor outcomes with a route to correction. The controls are cumulative. A disclosure cannot compensate for an unsafe input, and a human sign-off cannot repair a workflow that gives the reviewer no time or evidence.

5.1 Assess purpose before selecting a tool

The first question is what public-interest problem the newsroom is trying to solve. "Because the tool is available" is not a sufficient reason. Editors should define the task, the intended beneficiaries, the alternatives, and the consequence of not adopting AI. A proportionality test asks whether the use is suitable for the stated purpose, whether a less intrusive option is available, and whether expected benefits justify foreseeable harms. If a manual or simpler method can achieve the same result with less risk, it should remain an option.

5.2 Classify the task, not the brand name

Risk depends on the combination of task, data sensitivity, editorial influence, audience reach, and reversibility. The same transcription tool may be low risk for a public press conference and high risk for an interview with a vulnerable source. Figure 2 offers three illustrative tiers. Lower-risk uses still require approved tools and basic checks; moderate-risk uses need source verification and editorial approval; high-risk uses should be prohibited by default or allowed only after senior authorization, documented review, and a clear public-interest justification.

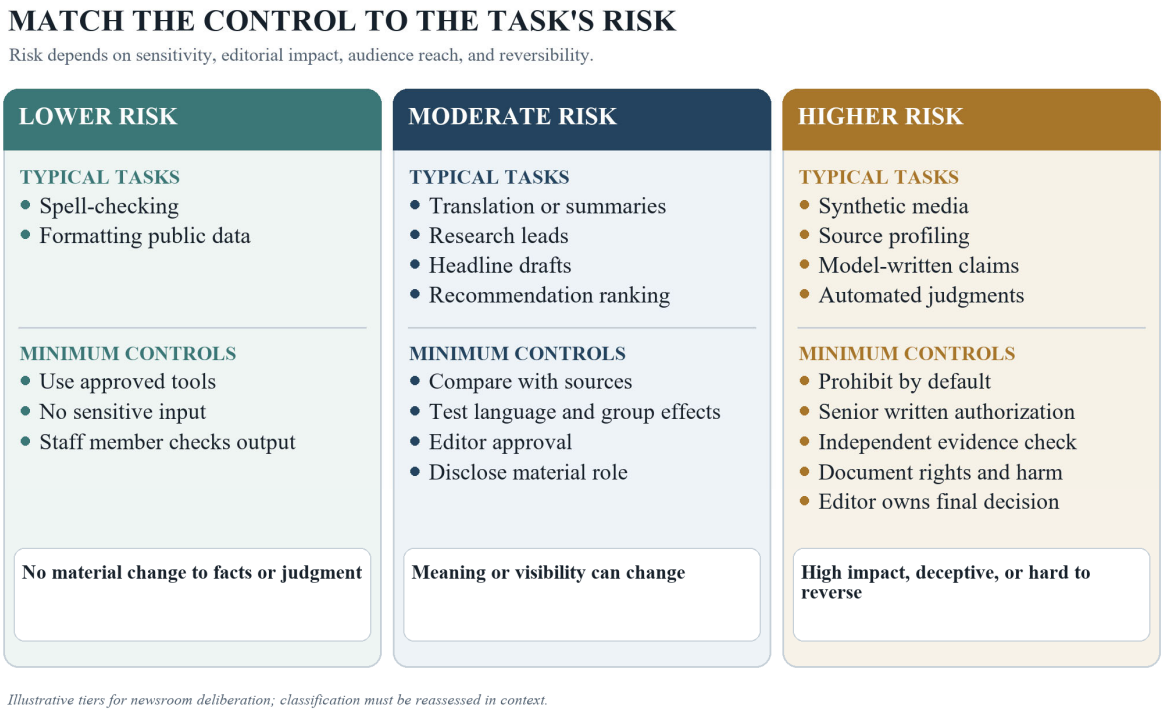


Figure 2. Illustrative task-risk tiers and minimum controls. The categories are a newsroom decision aid, not a quantitative risk score.

5.3 Preserve human editorial authority

Human oversight is not a ceremonial click. The responsible editor must understand what the model can and cannot establish, be able to inspect the source material, and have enough time and authority to challenge the output. The final editor remains accountable for publication, even if a vendor supplied the model or a product team configured the workflow. For claims about identifiable people, sensitive events, or public safety, an independent source check should be mandatory. No generated quotation, citation, image, or factual allegation should pass solely because it appears plausible.

Oversight can fail when staff are pressed to approve large volumes of output or when a system's confident tone discourages independent checking. A newsroom should set review limits,

train staff to identify common failure modes, and make rejection an ordinary outcome rather than a sign of poor productivity. Where human review cannot be performed with adequate context and time, the task should be narrowed or suspended. The accountable editor should be able to describe the checks completed, not merely attest that a person was present.

5.4 Protect privacy and test fairness

Before use, the newsroom should know what data the tool receives, whether those data are retained or used for training, where they are processed, and who can access them. Confidential sources, unpublished notes, personal data, and copyrighted materials should not be entered into unapproved services. Data minimization, access controls, retention limits, and documented deletion are practical safeguards. When a provider cannot answer basic questions, the newsroom should avoid sensitive use or choose another process.

Fairness review should examine how outputs differ across languages, communities, and subject areas that matter to the newsroom. This includes not only checking for biased language but also checking whether people and places appear, disappear, or are framed differently. In translation and recommendation, reviewers should compare outputs to the source and assess who gains visibility. Findings should lead to changes in prompts, configuration, or use restrictions, and not merely to a statement that bias is possible.

5.5 Disclose meaningful involvement and provide remedy

Transparency should answer a reader's practical questions: what was automated, what remained under human control, and how a significant error can be corrected. Disclosure is especially important when AI generates realistic media, substantially drafts factual claims, makes an editorial selection, or personalizes what readers see. The scope of the disclosure should match the system's influence. Audiences should have an accessible channel to report errors, request clarification, and receive a response. Corrections should identify the affected material and explain what was changed.

A layered disclosure can keep routine notices concise while making detail available on demand. A short note can identify AI's role, and a linked explanation can describe the task, the human review, and any important limitations. For synthetic visual or audio material, the notice should appear where the content is encountered and should not rely on a reader opening a policy page. Disclosures should be consistent enough that audiences can compare uses across stories without implying that every AI-assisted item has the same level of risk.

Figure 3 summarizes the framework as a continuous cycle, linking purpose, impact review, procurement, authorization, editorial review, disclosure, and remedy.

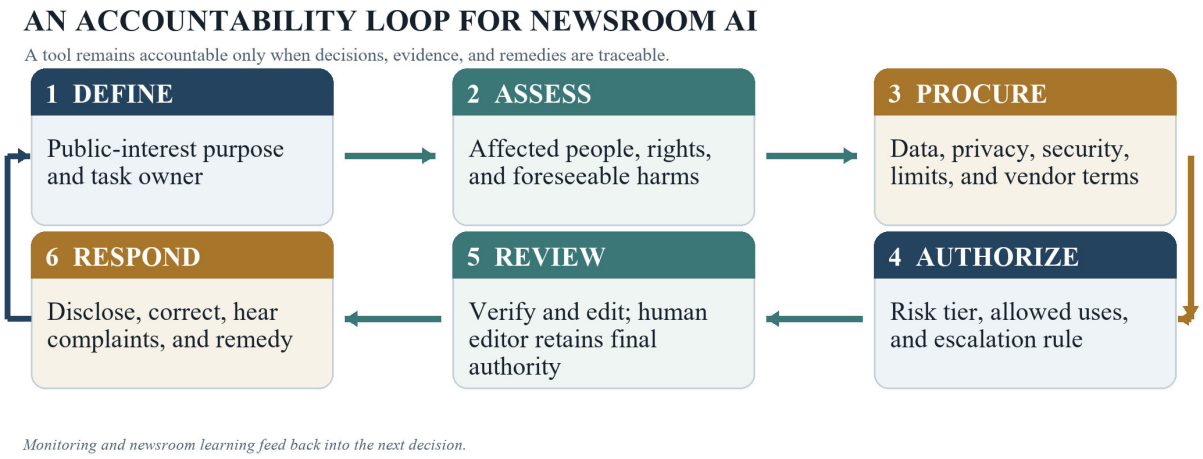


Figure 3. Accountability loop for newsroom AI. Proposed operating model informed by Council of Europe (2024), Diakopoulos (2015), and Sánchez-García et al. (2025).

5.6 Assign ownership and monitor the system

Every recurring AI use should have a named editorial owner, an approved purpose, a record of the system and data involved, and a review date. Procurement review should address security, provenance, retention, copyright, auditability, accessibility, and exit options. Teams should log incidents and near misses, assess whether harms fall unevenly on particular groups, and pause a tool when performance or provider terms materially change. The Council of Europe treats adoption as a circular decision that should be revisited as system performance and ethical conditions change (Council of Europe, 2024). As Figure 3 shows, monitoring should inform the next decision.

6. Discussion: governance as public-interest infrastructure

The framework treats governance as part of editorial infrastructure. It links ethical principles to decisions that newsrooms already make: commissioning, source protection, editing, ranking, procurement, correction, and workforce planning. This helps avoid two common errors. The first is to reduce ethics to a list of principles with no assigned owner. The second is to treat disclosure as a cure-all, although a reader label cannot undo privacy exposure, discriminatory selection, or an unverified claim.

This approach also keeps the distinction between assistance and delegation visible. AI may help a journalist find patterns or transform material, but editorial judgment includes deciding what matters, whose testimony counts, and what the public should know. When systems influence these choices, their design and operating assumptions should be open to scrutiny. Algorithmic accountability reporting offers a complementary public role: journalists can investigate how computational systems distribute power, shape opportunities, and conceal responsibility (Diakopoulos, 2015).

The framework is deliberately adaptable to different newsroom sizes. A small outlet may not have a separate AI ethics officer, but it can assign a problem owner, maintain a simple register of tools, restrict sensitive data, require editor approval for material generated content, and use a correction protocol. Shared training, procurement templates, and independent technical support can reduce the burden on under-resourced outlets. Ethical governance should not become another advantage available only to well-funded publishers.

Finally, news organizations should include journalists and affected communities in implementation. This is not only a matter of workplace consultation. Reporters understand how tools interact with sources and editorial routines; audiences can identify what information they need to assess AI involvement; and communities can challenge assumptions that standard datasets treat as neutral. Meaningful participation makes risk review more accurate and strengthens the legitimacy of resulting decisions.

Governance also protects editorial independence in the supply chain. Procurement terms should state whether prompts and uploads are retained, whether the provider may train on newsroom data, how system changes are communicated, and what access is available for investigation after an incident. Contracts should preserve an exit path so that a newsroom can change tools without losing its own archives or production capacity. Where these terms cannot be negotiated, editors should limit the system to work that does not require confidential inputs or unreviewable editorial influence.

7. Limitations and directions

This article offers a normative framework rather than evidence that a specific control will reduce harm by a measured amount. The selected literature is interdisciplinary and fast-moving, and the cited research does not cover every language, legal setting, newsroom type, or AI application. The risk tiers are illustrative; they must be tested against local editorial practice and should be revised when tools, provider terms, or audience expectations change.

Future research should examine how written policies are enacted during deadline pressure; whether disclosure helps readers understand different kinds of AI involvement; how recommendation systems affect local and minority-language coverage; and how newsroom AI changes training, employment, and editorial independence over time. Comparative research should include small and non-English newsrooms, where the cost of technical testing and the risk of linguistic underrepresentation may be especially consequential. Studies should also investigate procurement and vendor dependence, areas that receive less public attention than the content generated by a model.

8. Conclusion

AI can support journalism, but it cannot assume its obligations. Ethical use requires a public-interest purpose, understood data and effects, retained human editorial authority, and ways for audiences and affected people to contest and correct its contribution.

Newsrooms should govern AI by task across the lifecycle. Routine assistance may proceed with safeguards; systems that shape meaning, visibility, or decisions about people require stronger review. Deceptive or high-stakes automation should be barred by default, with any exception documented and authorized. Editors own decisions, vendors meet clear terms, workers participate, and monitoring continues after deployment. This makes transparency, fairness, privacy, proportionality, and accountability practical controls.

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Philosophical Sciences

АДАМ БОЛМЫСЫНЫҢ ГУМАНИСТІК БАСТАУЛАРЫ

Алимухамедова Дилафруз Собиткизи
2 курс магистранты, Абай атындағы Қазақ Ұлттық педагогикалық университеті, Философия мамандығы Алматы, Қазақстан
Ғылыми жетекші:
Рахимова Гульнара Дуйсеновна
ф.ғ.к.

Аңдатпа. Бұл мақалада адам болмысының гуманистік бастаулары философиялық антропология, этика және тұлға философиясы тұрғысынан талданады. Зерттеудің негізгі назарында адамды тек биологиялық не әлеуметтік құбылыс ретінде емес, өзіндік құндылығы, еркіндігі, жауапкершілігі және басқа адамға қатынасы арқылы айқындалатын тұтас болмыс ретінде түсіну мәселесі тұр. Гуманизмнің мазмұны адамды абсолюттендірумен шектелмей, оның қадір-қасиетін, ар-ожданын, таңдау еркіндігін және өз әрекетінің салдарын мойындау қабілетін бірлікте қарастыру арқылы ашылады. Мақалада гуманистік бастау тұлғаның ішкі автономиясы, эмпатия, диалог, өзгені мақсат ретінде қабылдау, моральдық жауапкершілік және мағыналы өмір құру ұстанымдарымен байланыстырылып түсіндіріледі. Канттың тұлға қадірі туралы идеялары, М. Бубердің диалогтық философиясы, Э. Фроммның гуманистік этикасы, В. Франклдың мағынаға ұмтылу тұжырымы және Абайдың адамгершілік туралы ойлары салыстырмалы түрде қарастырылады. Нәтижесінде гуманистік бастау адам табиғатына дайын күйде берілген қасиет емес, мәдениет, білім, моральдық тәжірибе және саналы таңдау арқылы дамитын экзистенциалдық-этикалық мүмкіндік деген тұжырым ұсынылады.

Түйін сөздер: адам болмысы, гуманизм, қадір-қасиет, еркіндік, жауапкершілік, диалог.

Кіріспе

Қазіргі қоғамдағы технологиялық жылдамдық, ақпараттық қысым және әлеуметтік байланыстардың өзгеруі адам туралы философиялық сұрақтарды екінші қатарға ығыстырмайды, керісінше олардың маңызын күшейтеді. Адамның мүмкіндігі артқан сайын оның еркіндігі мен жауапкершілігінің арақатынасы, өзге адамға қатынасының сипаты, өмірдің мағынасы мен қадір-қасиеттің өлшемдері бұрынғыдан да айқын көрінеді. Осы тұрғыдан алғанда гуманизм тек моральдық ұран немесе ізгі ниет жиынтығы емес. Ол адамның кім екені, өзін және өзгені қандай өлшем арқылы танитыны, еркін таңдауын қандай құндылықтармен шектейтіні жөніндегі іргелі философиялық бағдар болып табылады.

Адам болмысының гуманистік бастауларын талдау адамның табиғатын идеализациялауды емес, оның қайшылықты құрылымын мойындауды қажет етеді. Адам мейірімге де, қатыгездікке де, жауапкершілікке де, немқұрайлылыққа да қабілетті. Сондықтан гуманистік бастау адамның бойындағы автоматты түрде жүзеге асатын табиғи қасиет деп емес, белгілі бір құндылықтық бағдарды таңдауға, сақтауға және күнделікті әрекетте бекітуге мүмкіндік беретін ішкі әлеует деп қарастырылғаны жөн. Мұндай түсінік гуманизмді абстрактілі оптимизмнен ажыратып, оны нақты моральдық тәжірибемен байланыстырады.

Мақаланың мақсаты адам болмысының гуманистік бастауларын еркіндік, қадір-қасиет, жауапкершілік, диалог, эмпатия және мағына ұғымдары арқылы жүйелі түрде ашу болып табылады. Осы мақсатқа сәйкес философиялық антропологиядағы негізгі идеялар салыстырылады, олардың адамды тұтас субъект ретінде түсіндірудегі мүмкіндіктері айқындалады және гуманистік бағдардың қазіргі тұлғалық тәжірибедегі маңызы көрсетіледі.

Гуманистік ойдың өзегінде адамды құрал емес, өзіндік мақсат ретінде қабылдау қағидасы жатыр. И. Канттың мораль философиясында адам қадір-қасиеті оның бағасымен емес, дербес моральдық субъект болу қабілетімен түсіндіріледі. Адамның өзіндік құндылығы оның әлеуметтік мәртебесіне, пайдасына, біліміне немесе өзгелерге қаншалықты қолайлы екеніне тәуелді емес. Бұл қағида гуманистік антропология үшін шешуші мәнге ие, өйткені адамды сыртқы функциялар жиынтығына дейін қысқартуға қарсы тұрады [1, с. 276-278].

Адамның қадір-қасиетін мойындау тұлғаның даралығын да, оның әлеуметтік табиғатын да қатар ескеруді талап етеді. Даралық оқшауланумен тең емес. Керісінше, адамның бірегейлігі оның өз таңдауына жауап беру қабілетімен, құндылықтарды саналы игеруімен және өзгемен қатынас орнату тәсілімен ашылады. Адам өзін тек ішкі рефлексия арқылы ғана емес, басқа адамдармен қарым-қатынас үстінде де таниды. Сондықтан гуманистік болмыс өзіне бағытталған еркіндік пен өзгені мойындаудың тепе-теңдігіне негізделеді.

Осы тұрғыдан алғанда адамның өзіндік құндылығы екі қырдан көрінеді. Біріншісі, тұлғаның ішкі автономиясы. Адам өз өмірінің мәнін толықтай сыртқы нормалардан немесе көпшілік бағасынан алуға міндетті емес. Екіншісі, тұлға өзін өзге адамның еркіндігі мен қадір-қасиетін мойындау арқылы ғана толық жүзеге асырады. Егер еркіндік тек жеке мүддені жүзеге асыру құралына айналса, ол гуманистік мазмұнын жоғалтады. Сондықтан адам болмысының гуманистік негізі еркіндіктің өзіндік шектеу қабілетімен, яғни моральдық өлшеммен толықтырылады.

Адамның қадір-қасиеті оның әлсіздігі мен шектеулілігін жоққа шығармайды. Қайта, гуманистік ұстаным адамның қателесуі, күйзеліске түсуі, өмірлік дағдарысты бастан кешіруі мүмкін екенін қабылдай отырып, оны тек сәтсіздігі арқылы бағаламауды көздейді. Мұнда адамға құрмет оның жетістігіне емес, адамдық мәртебесіне негізделеді. Бұл тұжырым әлеуметтік қарым-қатынаста, білім беру кеңістігінде және кәсіби этикада ерекше маңызға ие.

Гуманизм еркіндікті адамның негізгі сипаттарының бірі ретінде қарастырады, алайда еркіндік жауапкершіліктен ажыратылған жағдайда ол адамның өзін де, өзгелерді де әлсірететін күшке айналуы мүмкін. Экзистенциалистік философия адамды дайын мәнге ие болмыс емес, өз әрекеті арқылы өзін қалыптастыратын субъект ретінде түсіндіреді. Ж.-П. Сартрдың пікірінше, адам таңдау жасамаудан да толықтай қашып құтыла алмайды, өйткені әрекетсіздік те белгілі бір позиция болып табылады [2, p. 22]. Осы тұрғыдан еркіндік тек мүмкіндік емес, жауапкершілік жүктейтін жағдай.

В. Франкл адам өмірінің басты қозғаушысы ретінде мағынаға ұмтылысты ерекше атап көрсетеді. Оның көзқарасында адам кез келген жағдайды еркін өзгерте алмауы мүмкін, бірақ сол жағдайға өзінің қатынасын таңдауға белгілі бір деңгейде қабілетті [3, с. 10]. Бұл идея гуманистік антропология үшін маңызды, себебі адам субъектілігін шексіз бақылау иллюзиясына емес, жағдайға жауап берудің ішкі мүмкіндігіне негіздейді. Еркіндіктің осындай түсінігі адамның шектеулерін де, қадір-қасиетін де қатар мойындайды.

Жауапкершілік адам әрекетінің нәтижесін алдын ала түгел білу дегенді білдірмейді. Ол өз таңдауының салдарын мойындауға, қажет болған жағдайда қателігін түзетуге және басқа адамның мүддесін есепке алуға дайын болуды білдіреді. Бұл жерде жауапкершілік қорқынышқа немесе жазадан қашуға негізделген сыртқы тәртіп емес, тұлғаның өзіндік моральдық позициясына айналады. Гуманистік тұлға үшін «маған не рұқсат?» деген сұрақтан гөрі «менің әрекетім адамдық қадір-қасиетке сәйкес келе ме?» деген сұрақ маңыздырақ.

Еркіндік пен жауапкершіліктің байланысы адамның өзін-өзі шектеу қабілетін де көрсетеді. Тек сыртқы тыйымдар арқылы реттелетін мінез-құлық тұлғаның ішкі гуманистік жетілуін білдірмейді. Ішкі этикалық өлшем қалыптасқанда адам өз мүмкіндігінің барлығын жүзеге асыру міндетті емес екенін түсінеді. Кейбір жағдайда өзгені қорғау, сенімді сақтау, әлсізге зиян келтірмеу немесе әділетсіз пайдадан бас тарту еркіндіктің ең жоғары көрінісіне айналады.

Адам болмысының гуманистік сипаты ең айқын түрде өзге адаммен қарым-қатынаста көрінеді. М. Бубердің «Мен–Сен» қатынасы туралы тұжырымы осы мәселені терең ашады. Бубердің пайымдауынша, адам өзгені объект, қызмет немесе құрал ретінде қабылдағанда «Мен–Ол» қатынасы қалыптасады, ал өзгені тұтас тұлға ретінде мойындағанда ғана шынайы диалог мүмкін болады [4, с. 23]. Бұл айырмашылық күнделікті қатынастардың моральдық сапасын бағалауда маңызды әдіснамалық мәнге ие.

Диалогтың гуманистік табиғаты пікірдің міндетті түрде сәйкес келуіне тәуелді емес. Екі адам бір мәселеге қарама-қарсы көзқараста бола отырып та бір-бірін құрметтеуі мүмкін. Демек, гуманизм келісімнің жоқтығын жаулыққа теңемеуді, адамның көзқарасын оның тұлғалық құндылығынан ажырата білуді талап етеді. Мұндай ұстаным әсіресе плюралистік қоғам жағдайында маңызды, өйткені бір кеңістікте әртүрлі дүниетанымдық, мәдени және моральдық ұстанымдар қатар өмір сүреді.

Эмпатия да гуманистік бастау құрылымында ерекше орын алады. Ол өзгенің күйін механикалық түрде қайталау емес, оның тәжірибесіне құрметпен жақындау қабілеті. Эмпатия адамға өз пікірін уақытша шетке ығыстырып, басқа адамның жағдайын түсінуге мүмкіндік береді. Алайда эмпатия моральдық өлшемнің орнын толық баса алмайды. Өзгені түсіну оның барлық әрекетін ақтау деген сөз емес. Сондықтан гуманистік қатынас түсіну мен принципшілдіктің, жанашырлық пен жауапкершіліктің үйлесімін қажет етеді.

Э. Левинас өзге адамның жүзін моральдық жауапкершіліктің бастапқы тәжірибесі ретінде қарастырды. Оның философиясында этика теориялық білімнен бұрын келетін қатынас ретінде көрінеді [5, с. 290]. Бұл идея адам болмысының гуманистік негізін тек ішкі қасиеттермен шектемей, тұлғаның өзгенің алдында жауап беруінен туындайтын қатынастық сипатпен толықтырады.

Гуманизмнің маңызды қыры адамның тек құқықтар иесі ғана емес, өзін өзгертуге қабілетті рухани субъект екендігін мойындаудан көрінеді. Э. Фромм гуманистік этикада адамның ізгілігін оның өмірді дамыту, өнімді әрекет ету, сүйіспеншілік пен ақылға сүйену қабілетімен байланыстырады [6, с. 12]. Оның көзқарасында адам табиғаты толық аяқталған құрылым емес. Ол өзіндік мүмкіндіктерді жүзеге асыру барысында қалыптасады. Осы мағынада гуманизм адамның барлық қалауына рұқсат беру емес, оның адамдық әлеуетін тереңдететін өмір салтын таңдау.

Рухани кемелдену өзін мінсіз деп жариялаудан басталмайды. Ол адамның өзінің ішкі қайшылықтарын, әлсіздігін және өзімшілдігін байқап, олармен саналы жұмыс істеуінен басталады. Сондықтан гуманистік даму өз-өзіне сыни қатынасты да қамтиды. Тұлға өзін үнемі ақтай бермей, өз әрекетінің басқа адамға қалай әсер еткенін бағалай алған кезде моральдық рефлексия пайда болады.

Қазақ философиялық ойында да адамның адамгершілік жетілуі сыртқы мәртебеден жоғары қойылған. Абайдың «толық адам» туралы ойлары ақыл, қайрат және жүректің тұтастығына сүйенеді. Абай үшін адамдық кемелдену біліммен ғана өлшенбейді, өйткені білімнің өзі ар-ұят пен әділеттен ажыраған жағдайда адамды ізгі ете алмайды [7, 117-119 бб.]. Бұл қағида қазіргі гуманистік философиямен үндеседі. Тұлғаның зияткерлік мүмкіндігі мен моральдық жауапкершілігі бірлікте болғанда ғана адам өз болмысын толық жүзеге асыра алады.

Осы негізде адам болмысының гуманистік бастауларын бірнеше өзара байланысты өлшем арқылы көрсетуге болады.

Кесте 1 – Адам болмысының гуманистік бастауларының негізгі өлшемдері

Өлшем	Философиялық мазмұны	Тұлғалық көрінісі
Қадір-қасиет	Адамды өзіндік мақсат ретінде мойындау	Өзін және өзгені құралға айналдырмау
Еркіндік	Саналы таңдау және ішкі автономия	Құндылыққа сүйеніп шешім қабылдау
Жауапкершілік	Таңдаудың салдарын мойындау	Қателікті түзетуге және жауап беруге даярлық
Диалог	Өзгені дербес тұлға ретінде қабылдау	Тыңдау, пікір айырмашылығын құрметтеу
Эмпатия	Өзгенің тәжірибесіне сезімталдық	Жанашырлық пен моральдық ұстанымды үйлестіру
Мағына	Өмірлік бағыт пен құндылықтық тұтастық	Өмірді тек пайдамен өлшемеу

1-кестеде көрсетілген өлшемдер гуманистік бастау бір ғана эмоциялық ізгілікпен шектелмейтінін көрсетеді. Оның құрылымы тұлғаның ішкі автономиясын да, өзге адам алдындағы моральдық міндетін де қамтиды. Сондықтан гуманистік кемелдену адамның «өзін жүзеге асыруы» мен «өзгені мойындауы» арасындағы үйлесім арқылы қалыптасады. К. Роджерс тұлғаның ашықтық, өзін қабылдау және тәжірибеге сенім арту қабілетін жетілген тұлғаның маңызды белгісі ретінде қарастырса [8, с. 170-171], А. Маслоу өзін-өзі жүзеге асыруды адамның жоғары мүмкіндіктерін дамыту үдерісімен байланыстырады. Бұл көзқарастар гуманизмнің тұлғалық өсуге бағытталған қырын айқындайды.

Қазіргі әлеуметтік кеңістікте гуманистік бастау адамның жеке моральдық қасиетімен ғана шектелмей, қоғамдық қатынастардың сапасын анықтайтын өлшемге айналады. Цифрлық коммуникация адамның бір-бірімен байланысу мүмкіндігін кеңейтті, бірақ сонымен бірге тұлғаны дерек, профиль, аудитория немесе статистикалық көрсеткіш деңгейінде қабылдау қаупін күшейтті. Мұндай жағдайда гуманистік бағдар адамның артында қайталанбас тәжірибесі, сезімі, өмірлік тарихы бар субъект тұрғанын еске салады. Бұл қағида әсіресе әлеуметтік желідегі пікірталас, кәсіби ортадағы бәсеке және білім беру үдерісіндегі бағалау кезінде маңызды. Адамды тек нәтижесімен өлшеу оның тұлғалық тұтастығын назардан тыс қалдырады.

Гуманистік ұстаным әлеуметтік әділеттілік мәселесіне де тікелей қатысты. Адам қадір-қасиетін мойындау барлығын бірдей ету дегенді білдірмейді, бірақ адамның негізгі құқықтары мен моральдық мәртебесі әлеуметтік жағдайға тәуелді болмауға тиіс деген талапты білдіреді. Осы тұрғыдан гуманизм әлсіз топтарға қамқорлықты тек жанашырлық ретінде емес, олардың субъектілігін және дербес таңдау құқығын мойындау ретінде қарастырады. Альберт Швейцердің өмірге құрмет қағидасы да адамгершілікті абстрактілі ережеден тірі болмысқа жауапты қатынасқа көшіреді. Бұл принцип адамға ғана емес, адамның табиғатпен байланысына да этикалық өлшем береді.

Білім беру кеңістігінде гуманистік бастау білім алушыны дайын ақпаратты қабылдайтын объект емес, өзіндік ойы мен жауапкершілігі бар тұлға ретінде қарастырудан көрінеді. Мұнда мұғалімнің міндеті тек білім беру емес, адамның өз пікірін дәлелдеуге, қателесуге, қайта қарауға және өзгенің көзқарасын тыңдауға мүмкіндік беретін мәдени орта

қалыптастыру. Гуманистік білім тұлғаның автономиясын күшейте отырып, оны ортақ жауапкершіліктен ажыратпайды. Сондықтан еркін ойлау тәртіпсіздікпен, ал талап қою тұлғаны кемсітумен теңестірілмеуге тиіс. Адамды құрметтеу нақты талаптарды жою емес, сол талаптарды тұлғаның қадір-қасиетін сақтай отырып ұсыну мәдениетін білдіреді. Осыдан гуманизмнің қазіргі мәні адамның мүмкіндігін шексіз мадақтаудан емес, оның әлсіздігі мен жауапкершілігін қатар мойындаудан көрінеді. Технология, нарық немесе әлеуметтік бедел адам өмірінің құндылығын анықтайтын соңғы өлшем бола алмайды. Гуманистік философияның тұрақты маңызы да осында: ол өзгермелі қоғамдық жағдайлардың ішінде адамның адамға қатынасын негізгі моральдық сынақ ретінде сақтайды. Тұлғаның шынайы жетілуі өзінің мүмкіндігін көбейтумен ғана емес, сол мүмкіндікті қандай мақсатқа және қандай моральдық шекара ішінде пайдаланатынымен өлшенеді.

Жүргізілген философиялық талдау адам болмысының гуманистік бастауларын бір ғана моральдық қасиетпен түсіндіру жеткіліксіз екенін көрсетеді. Гуманизм адамның өзіндік құндылығын мойындаудан басталғанымен, оның мазмұны еркіндік, жауапкершілік, диалог, эмпатия, ар-ождан және мағынаға ұмтылу арқылы толық ашылады. Бұл элементтер бір-бірінен ажыратылған жағдайда гуманистік бағдар өзінің тұтастығын жоғалтады. Еркіндік жауапкершіліксіз өзімшілдікке, эмпатия принципсіз жұмсақтыққа, ал өзіндік қадірді мойындау өзгенің қадірін елемеуге айналуы мүмкін.

Адамның гуманистік табиғаты дайын және өзгермейтін қасиет ретінде емес, жүзеге асырылуға тиіс мүмкіндік ретінде қарастырылғаны орынды. Тұлға өзінің адамдық сапасын әрбір нақты таңдауда, қарым-қатынаста және моральдық шешімде бекітеді. Сондықтан гуманизмнің өміршеңдігі абстрактілі декларацияларға емес, адамның басқа адамға қалай қарайтынына, билік пен мүмкіндікке ие болғанда өзін қалай шектейтініне, әлсізді көргенде қандай ұстаным таңдайтынына байланысты. Осы тұрғыдан адам болмысының гуманистік бастаулары тұлғаның ішкі еркіндігі мен әлеуметтік жауапкершілігінің тоғысқан жерінен көрінеді. Адам өзін құрметтей отырып өзгені де мақсат ретінде қабылдағанда, өзінің еркіндігін басқа адамның қадір-қасиетімен үйлестіргенде және өмір мәнін тек жеке пайдамен өлшемегенде гуманистік бағдар нақты мазмұнға ие болады. Сондықтан гуманизмді адам табиғаты туралы оптимистік тезис ретінде емес, адамның адам болып қалуына мүмкіндік беретін саналы, үздіксіз және жауапты рухани тәжірибе ретінде түсіндіру неғұрлым негізді болып табылады.

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ЦИФРЛЫҚ ҚОҒАМДАҒЫ ЕҢБЕК ФИЛОСОФИЯСЫ: ЖАҢА МҮМКІНДІКТЕР МЕН ҚҰНДЫЛЫҚТАР

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Аңдатпа. *Бұл мақалада еңбек құндылығының қазіргі қоғамдағы орны мен адамның жеке тұлғалық даму сипатындағы қалыптасуына әсері қарастырылады. Цифрландыру, әлеуметтік-экономикалық өзгерістер жағдайындағы еңбек құндылығының адам өміріндегі орны мен маңыздылығы талданадаы. Еңбек құндылығының адам өміріндегі кәсіби өзін-өзі дамытуы, шығармашылық қабілеті мен тұлғалық әлеуетінің жүзеге асыру мәселелері қарастырылады.*

Түйін сөздер: *еңбек, цифрлық қоғам, уақыт, цифрлық технологиялар, жасанды интеллект*

Қазіргі цифрлық дәуір адамзат өмірінің сан алуан саласын өзгертіп, еңбек пен уақыттың қадіріне деген көзқарасты жаңаша пайымдауға жетелеп отыр. Жасанды интеллект, автоматтандыру жүйелері мен цифрлық технологиялар бұрын едәуір күш пен ұзақ уақытты қажет еткен міндеттерді қысқа мерзімде орындауға мүмкіндік береді. Ақпаратқа қол жеткізу жеңілдеп, білім көкжиегі кеңейіп, адамның мақсатқа жету жолдары да өзгеруде. Осы тұрғыдан алғанда, цифрлық қоғамның басты мүмкіндіктерінің бірі — уақытты үнемдеу. Өйткені ақшадан айырылсаң, белгілі бір дүниеңнен айырыласың, ал уақытты жоғалтсаң, ғұмырыңның қайтып келмес бір бөлшегін жоғалтасың. Алайда уақытты үнемдеу оның қадірін терең түсініп, оны саналы пайдалана білумен әрдайым ұштаса ма? Технологиялар адамның мүмкіндіктерін кеңейткен сайын, оның өз уақытына, еңбегіне және рухани дамуына деген көзқарасы қалай өзгеріп келеді?

Уақыт — адам өміріндегі орны толмас асыл құндылықтардың бірі. Өйткені өткен шақты кері қайтару мүмкін емес; ал уақыттың қалай өткені адамның өмірлік тәжірибесіне, біліміне және тұлғалық қалыптасуына әсер етеді. Абай Құнанбайұлының «Ғұмыр өзі ағып жатқан су сияқты, тоқтамақ жоқ» деген сөзі де тіршіліктің өткіншілігін аңғартып, әр сәттің мәнін бағалауға үндейді.

Цифрлық технологиялар көптеген міндетті орындауға кететін уақытты қысқартуға мүмкіндік береді. Бұрын бірнеше сағатқа созылатын жұмыс бүгінде әлдеқайда жылдам орындалады. Бұл адамға өзге істерге ден қоюға, жаңа білім игеруге, шығармашылықпен айналысуға және қабілетін шыңдауға жол ашады. Дегенмен уақыттың үнемделуі оны міндетті түрде ұтымды пайдалануға әкелмейді. Кейде технологияның көмегімен босай түскен уақыт әлеуметтік желілерде ұзақ ақтаруға немесе ақпаратты мақсатсыз тұтынуға жұмсалады. Сөйтіп, адамның дамуына қызмет етуі тиіс мүмкіндік әп-сәтте өте шыққан уақытқа айналуы ықтимал. Сондықтан цифрлық қоғамдағы маңызды мәселе — уақытты үнемдеумен шектелмей, оның қадірін ұғынып, оны саналы жарату мәдениетін қалыптастыру.

Бұл мәселе қай уақыт аралығында болсын өз маңызын жоймайды, өйткені ол адам болмысының жетілуімен тығыз байланысты. Оның мәнін қазақ ойшылдарының мұрасымен сабақтастыра қарастыруға болады. Абай Құнанбайұлының отыз бірінші қара сөзінде естігенді есте сақтау, ой елегінен өткізу және ақыл мен ғылымға кедергі келтіретін әдеттерден арылу мәселесі қозғалады. Ойшыл былай деп жазады: «Ой кеселдері: уайымсыз салғырттық, ойыншы-күлкішілдік, я бір қайғыға салыну, я бір нәрсеге құмарлық пайда болу секілді. Бұл төрт нәрсе — күллі ақыл мен ғылымды тоздыратұғын нәрселер» [1]. Абайдың бұл пайымын қазіргі цифрлық қоғам жағдайында да жаңаша зерделеуге болады. Бүгінде адамның назарын өзіне тартатын ақпарат көздері өте көп. Әлеуметтік желілер, қысқа бейнероликтер мен үздіксіз жаңарып отыратын ақпарат ағыны уақытты ғана емес, зейінді шоғырландырып, терең ойлануға қажет ішкі тыныштықты да жұтуы мүмкін. Әрине, Абайдың бұл пікірін бүгінгі әлеуметтік желілерге тікелей қатысты айтылған тұжырым деп қабылдауға болмайды. Дегенмен ойға тұсау болатын әдеттер жөніндегі оның пайымы қазіргі адамның уақыт пен зейінді пайдалану мәдениетін талдауға негіз бола алады. Егер адам өз назарын саналы түрде басқара алмаса, технология ұсынған мол мүмкіндік те оның дамуына толық қызмет ете алмайды. Демек, цифрлық дәуірде уақытты бағалау — оны үнемдеу ғана емес, ойға, білімге және рухани өсуге орын беру.

Абай Құнанбайұлының отыз екінші қара сөзі де осы мәселені тереңірек түсінуге жол ашады. Ойшыл білім мен ғылымды меңгерудің шарттарын саралап, талап пен үздіксіз ізденістің маңызын көрсетеді. Ол: «Білім – ғылым үйренбекке талап қылушыларға әуелі білмек керек. Талаптың өзінің біраз шарттары бар. Оларды білмек керек. Оларды білмей, іздегенмен табылмас» [2], - деп жазады. Бұл ой қазіргі цифрлық қоғамдағы үздіксіз даму ұғымымен сабақтас. Бүгінде технологиялар жастарға білім алуға, тәжірибе жинақтауға және белгілі бір нәтижеге бұрынғыдан жылдамырақ жетуге мүмкіндік береді. Алайда жылдам жетістік адамның даму жолы аяқталды дегенді білдірмейді. Керісінше, әрбір белес жаңа міндеттер мен мүмкіндіктердің бастауы. Бір мақсатқа жеткен соң келесі мақсаттың туындауы — дамудың табиғи жалғасы. Сондықтан білім мен еңбекті белгілі бір нәтижеге жеткізетін құрал ғана емес, ғұмыр бойы жалғасатын таным мен ізденіс жолы ретінде қарастырған жөн.

Еңбек — адамның мінезін шыңдап, тұлғалық болмысын қалыптастыратын өмірлік мектеп. Осы мектепте адам өз мүмкіндігін танып, қателігінен сабақ алады, жауапкершілікті сезінеді және қиындықты еңсеруге үйренеді. Оның құндылығы тек соңғы нәтижемен өлшенбейді, өйткені сол нәтижеге жету жолында адамның өзі де өзгеріп, толысады. Технологиялар кейбір әрекетті жеңілдетіп, уақытты үнемдегенімен, өмірлік тәжірибені, табандылықты және өз ісіне деген жауапкершілікті толығымен алмастыра алмайды. Технология уақытты ұтымды ұйымдастыруға көмектессе, еңбек сол уақытты мағыналы іске арнауға үйретеді. Халық даналығындағы «Еңбек адамның көркі, адам заманның көркі», «Еңбегі көптің өнбегі көп.» деген мақал-мәтелдер адал еңбектің, табандылық пен төзімнің мәнін танытады. Адам өзі жақсы көретін және өзіне жақын жұмыспен айналысқанда, оның міндеттемесі қуаныш әкеледі. Оның өзіне ғана емес, басқа адамдарға да, қоғамға да, елге де пайдасын тигізіп, өнегелі үлгі көрсететіні анық. Сондай-ақ, еңбек адам өмірінің негізгі көрсеткіші деп айтуға болады. Себебі, адам өзінің ұлылығын, көркемдік мінезін тек еңбек арқылы ғана көрсетеді. Адам әрқашан жұмыспен байланыста болады, сондықтан әркім өз жанының сүйікті ісімен айналысып, адал еңбек етуі керек. Сонымен бірге ол өзіне ғана емес, қоғамға, бүкіл адамзатқа пайдасын тигізеді.

Абай Құнанбайұлының ойларына қайта оралып, еңбекке қатысты көзқарасына тереңірек үңілсек, оның мәнін екі түрлі қырынан тануға болады. Біріншісі — адамның тек өз басының қамы мен материалдық пайдасын көздейтін еңбек. Абай: «Өзің үшін еңбек қылсаң, өзі үшін оттаған хайуанның бірі боласың», — деп, еңбекті күнкөріс пен жеке пайда шеңберінде шектелген түсінікті көрсетеді. Екіншісі — адамшылық борышын өтеуге, қоғам

мен адамзат игілігіне қызмет етуге бағытталған еңбек. Ойшылдың «Адамшылықтың қарызы үшін еңбек қылсаң — Алланың сүйген құлының бірі боласың» деген сөзі еңбектің моральдық әрі рухани мәнін айқындайды.

Абай Құнанбайұлының «Аш қарын жұбана ма майлы ас жемей?» атты өлеңінде:

Еңбек жоқ, харекет жоқ қазақ кедей,
Тамақ аңдып қайтеді тентіремей?
Ет пен қымыз сықылды ас жоқ дейді,

Ол немене жоқтықтың әсері емей? [5, 223 б.] - деп, халықтың жағдайын сипаттайды. Өлең жолдарынан көрініп тұрғандай, еңбек етпеу адамды азғындыққа, тамақ құдалауға жетелейді. Еңбек етпеген адам дәулеттің дәмін тата алмайды. Абайдың «Ғылым таппай мақтанба» өлеңінде талап пен еңбек адамды кемелдікке бастайтын бес асыл істің қатарында атайды. Ақын:

«Талап, еңбек, терең ой,
Қанағат, рақым, ойлап қой» - деп, адам бойында болуы қажет негізгі қасиеттерді тізіп айтып кеткен. Мұндағы талап — білімге ұмтылыс болса, еңбек — сол білім мен қабілетті іске асырудың жолы. Қазақ дүниетанымында адал еңбек адамның рухани және материалдық тұрғыдан жетілуіне ықпал ететін маңызды құндылық ретінде бағаланады. Бұл идея Абайдың «толық адам» тұжырымдамасымен байланысты, өйткені кемелдікке жету білімді, қайратты және адамгершілікті өзара үйлестіруді талап етеді. Қазіргі технологиялар адамның жұмысын жеңілдетуі мүмкін, алайда еңбектің мақсатын және оның адам мен қоғам үшін мәнін айқындау жауапкершілігі адамның өзінде қалатының ұмытпауымыз тиіс.

Жасанды интеллект дәуірінде бұл ойдың маңызы арта түседі. Жасанды интеллект және т.б. инновациялық технологиялар белгілі бір жұмысты жылдам орындауға көмектескенімен, білім жинау, іздену, тәжірибе арқылы үйрену және өз әрекетіне жауап беру сияқты үдерістерді толық алмастыра алмайды. Сондықтан жасанды интеллектіні еңбектен жалтарудың амалы емес, адамның мүмкіндігін кеңейтетін құрал ретінде пайдаланған жөн. Уақытты үнемдеу адам сол уақытты саналы мақсаттарға бағыттағанда ғана шынайы мәнге ие болады.

Бұл мәселе Шәкәрім Құдайбердіұлының философиялық мұрасында қарастырсақ.. Оның «Үш анық» еңбегінде адам болмысы, ар-ұждан және рухани-адамгершілік мәселелері терең қозғалады. Шәкәрім ұжданның адам өміріндегі маңызын атап көрсетіп, оны «нысап, әділет, мейірім» ұғымдарымен байланыстырады [4]. Бұл пайымды қазіргі қоғамдағы еңбек пен жетістік мәселесін талдауда да басшылыққа ала отырып болып жатқан мәселерді талдайық.. Бүгінде қоғамдағы елеулі өзгерістердің бірі — жастардың белгілі бір нәтижеге қысқа мерзімде қол жеткізу мүмкіндігінің артуы. Алайда бұл үрдіс өзгелермен салыстыруды күшейтіп, үнемі алға ұмтылуға деген қысым тудырады. Әлеуметтік желілерде өзгенің жетістігін бақылау кейде адамды өзінің даму жолын бағалаудан гөрі, біреуден қалып қоймауға тырысуға итермелейді. Соның салдарынан үздіксіз жетістікке ұмтылу жан дүниені қажытып, адамның өз өміріндегі қарапайым қуаныштарды сезінуіне кедергі келтіруі ықтимал. Осы тұста Абай Құнанбайұлының:

«Ойға түстім, толғандым,
Өз мінімді қолға алдым» - деген өлең жолдары айрықша мәнге ие. Бұл жолдар адамның өзіне сын көзбен қарап, кемшілігін танып, өзгеруге талпынуының маңызын аңғартады. Өзгелермен жарысып, олардың нәтижесіне жетуге тырысқаннан гөрі, өз болмысына үңіліп, кешегі күнмен салыстырғанда бүгін бір қадам болса да ілгерілеуге ұмтылғаны жөн. Бұл міндетті түрде үлкен жетістікке жету деген сөз емес: жаңа нәрсе үйрену, қателіктен сабақ алу немесе өзіңе уақыт бөлу де дамудың бір бөлігі. Өйткені әр адамның өмір жолы мен өсу қарқыны әртүрлі. Нағыз даму — өзгеден озып шығу емес, кешегі өзіңнен

асып, күн сайын аз да болса кемелдене түсу. Жетістікке ұмтылу адамды өз болмысынан алыстатпай, керісінше, өзін тереңірек тануына және өмірін саналы құруына жол ашуы керек.

Қазақ әдебиетіндегі еңбек пен технологиялық ілгерілеу мәселесін сөз еткенде, Ыбырай Алтынсариннің ағартушылық мұрасына да назар аударған жөн. Оның «Өнер-білім бар жұрттар» өлеңінде ғылым мен техниканың адам мүмкіндігін кеңейтетін қуаты бейнеленеді. Ақын:

«Айшылық алыс жерлерден,
Көзіңді ашып-жұмғанша,
Жылдам хабар алғызды» [3], — деп, техникалық жаңалықтардың тіршілікке әкелетін өзгерістерін суреттейді. Ыбырай Алтынсарин бұл өлеңінде өз дәуіріндегі ғылыми-техникалық дамудың мүмкіндіктерін танытса, оның идеясын бүгінгі цифрлық қоғам жағдайында жаңа қырынан пайымдағым келіп тұр. Қазіргі технологиялардың мүмкіндіктерінің арқасында адамдармен жедел байланыс орнату жеңілдеді. Мәселен, алыста жүрген жақындарымызға кез келген уақытта қоңырау шалып, хал-жағдайын біле аламыз. Алайда мұндай мүмкіндіктердің күнделікті өмірімізге енуі кейде олардың қадірін сезінбей қалуымызға да әкеледі. Кейде хабарлама жіберумен шектеліп, жақындарымызға қоңырау шалуға немесе асықпай, шынайы әңгімелесуге уақыт бөлмейміз. Бұл технологияның дамуы қарым-қатынастың сапасына өздігінен кепіл бола алмайтынын аңғартады. Сондықтан цифрлық мүмкіндіктерді тиімді пайдаланумен қатар, жақындарымызға көңіл бөліп, олардың қадірін білуіміз қажет. Өйткені технология адамдарды байланыстыра алады, бірақ олардың арасындағы шынайы жылылық пен ықыласты алмастыра алмайды. Технологиялық прогрестің мәні оның мүмкіндіктерінің молдығында ғана емес, сол мүмкіндіктерді адамгершілікпен әрі орынды пайдалана білуде. Қорытындылай келе, автоматтандырудың берер мүмкіндігінің көп, ол мүмкіндіктер өздігінен іске аспайды: бәрі адамның таңдауына, әдетіне және уақытты пайдалану мәдениетіне байланысты.

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ҚАЗАҚ ДҮНИЕТАНЫМЫНДАҒЫ АДАМ МЕН ТАБИҒАТ ҮЙЛЕСІМІ

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Түйіндеме. Мақалада қазақ халқының дәстүрлі дүниетанымындағы адам мен табиғаттың өзара байланысы қарастырылады. Табиғаттың көшпелі өмір салтындағы орны, туған жерге деген құрмет, халықтық салт-дәстүрлер мен наным-сенімдердің экологиялық мазмұны талданады. Ата-бабамыздың бізге дейінгі адам мен табиғат үйлесімін қалай сақтағанын, қалай пайдаланғанын қозғайтын болады. Адам мен табиғат үйлесімі ашық көрсетіледі.

Кілт сөздері: Адам, табиғат, Жер-ана, дүниетаным, көшпелі мәдениет, кие мен обал, табиғат тепе-теңдігі.

Қазақ халқы ежелден табиғат пен адам үйлесімділігін сақтап келеді. Кие мен обалды анық көрсету арқылы табиғаты қадірлі көрсетеді. Жерді өмірдің бастауы етіп көрсету арқылы оған Ана деген аты бөліскен. Жер-ана сөзін естіген әрбір қазақ баласы жерді өзінің анасы ретінде көріп кие тұтады. Көшпелі мәдениетімізде табиғатпен тепе теңдік сақтау арқылы баратын немесе келктін жолын дәл анық білген. Табиғат тепе теңдіген сақтап келер ұрпаққа мұра етіп қалдырған. Қазақ халқы табиғатқа келгенде кие мен обалға аса қатты мән берген, табиғат үйлесімділігіне қауіп төндірмеу үшін барын салған, жәйдан жәй аң атпаған немесе төлдеу кезінде аңға шықпаған егер мұндай жағдайда киесі ұрады деп адамдарды мұндай іс әрекетерден сақтаған. Кие сөзін қолдану арқылы жан жануар мәртебесін арттырған. Ал обал арқылы оларды бостан босқа қырудың алдын алған, осы сөздерді халқымыздың қанына сіңдіру үшін мақалдармен аңыз ауыз әдебиетермен бабадан ұрпаққа жеткізіп отырған. Аққуды атпа

“Атпа, достым, оларды,
Бұзба тобын олардың,
Тау бұлбұлы солардың,
Мен жырына құмармын.” [1. 599 б.]

Табиғат пен адам арасындағы байланыс екіжақты сипатқа ие. Бір жағынан, табиғи орта адамның өмір сүру жағдайын қалыптастырады. Климат, топырақ, су, өсімдіктер мен жануарлар дүниесі шаруашылық түрлеріне, қоныстану ерекшеліктеріне және қоғамдық дамуға әсер етеді. Екінші жағынан, адам еңбек, ғылым және техника арқылы табиғи ортаға ықпал етеді. Ол жерді өңдейді, су ресурстарын пайдаланады, қалалар мен өндіріс орындарын салады. Мұндай әрекеттер қоғамның дамуына мүмкіндік бергенімен, табиғи тепе-теңдік ескерілмесе, қоршаған ортаға зиян келтіруі мүмкін.

Философиялық тұрғыдан алғанда, үйлесім адамның табиғатқа үстемдік жүргізуі емес, оның заңдылықтарын түсініп, сол заңдылықтарға сай әрекет етуі арқылы қалыптасады. Адам

табиғаттың иесі емес, оның бір бөлшегі екенін сезінгенде ғана жауапты қарым-қатынас орнайды. Қазақ ойшылдарының еңбектерінде де табиғат пен адам жанының үндестігі, туған жерге сүйіспеншілік және қоршаған ортаның адам болмысына әсері кеңінен қарастырылған. Мәселен, Абай шығармаларында табиғат көріністері адамның көңіл күйімен, өмір салтымен және дүниені тануымен сабақтастырыла суреттеледі [2, 176–177 бб.].

Табиғат адамға тек материалдық игілік беріп қана қоймайды. Ол эстетикалық ләззат сыйлап, адамның ой-өрісін кеңейтеді, рухани дүниесін байытады. Таудың асқақтығы, даланың кеңдігі, өзеннің ағысы мен орманның тыныштығы адамда сұлулықты сезіну қабілетін қалыптастырады. Сондықтан табиғатты қорғау – тек шаруашылық немесе құқықтық міндет емес, сонымен қатар адамгершілік және мәдени жауапкершілік.

Қазақ халқының дүниетанымында «Жер-Ана», «атамекен», «туған жер», «су – тіршілік көзі» сияқты ұғымдар терең мағынаға ие. Жерді анаға теңеу табиғатқа деген құрметті, оның адам өміріндегі орнын және оны қорғау қажеттігін білдіреді. Туған жерге деген сүйіспеншілік тек белгілі бір мекенге байланып қалу емес, сол жердің табиғатын, тарихын, суын, жайылымын және тіршілік иелерін қадірлеу деген сөз.

Көшпелі шаруашылықта табиғи ресурстарды маусымға қарай пайдалану тәжірибесі қалыптасты. Малшылар жайылымды бір жерде ұзақ уақыт пайдаланбауға, малды көктемгі, жазғы, күзгі және қысқы қоныстарға көшіруге мән берген. Мұндай тәжірибе жайылымның қалпына келуіне жағдай жасап, табиғи ресурстарды тиімді пайдалануға көмектесті. Табиғат құбылыстарын бақылау арқылы халық ауа райын болжау, су көздерін табу, өсімдіктер мен жануарлардың ерекшеліктерін ажырату жөнінде мол тәжірибе жинақтады.

Халықтық тыйым сөздер мен салт-дәстүрлер де экологиялық тәрбиенің қызметін атқарды. «Бұлақ көрсең, көзін аш», «Суға түкірме», «Көк шөпті жұлма», «Құстың ұясын бұзба» деген нақылдар табиғат нысандарына жанашырлықпен қарауға үндейді. Бұл қағидалар арқылы жас ұрпаққа суды ластамау, өсімдіктерді орынсыз жұлмау, жануарларға зиян келтірмеу сияқты қарапайым, бірақ маңызды ережелер үйретілді. Қазіргі зерттеулерде қазақ мәдениетіндегі «Жер-Ана» түсінігі, жер-суға қатысты нанымдар мен табиғатты қорғау тыйымдары экологиялық этиканың мәдени негіздері ретінде қарастырылады [3, 36–38 б.].

Дәстүрлі дүниетанымның құндылығы – табиғатты адамнан бөлек құбылыс ретінде емес, ортақ тіршіліктің негізі ретінде қабылдауында. Бұл көзқарас бүгінгі қоғам үшін де маңызды. Өйткені табиғатты қорғау тек мемлекеттік мекемелердің немесе эколог мамандардың міндеті емес, әрбір адамның күнделікті өмірінен басталуы тиіс.

Қазіргі кезеңде адам мен табиғат арасындағы үйлесімге бірқатар қауіп төніп отыр. Өнеркәсіптің дамуы, көлік санының көбеюі, тұрмыстық қалдықтардың артуы, орман алқаптарының азаюы, су мен ауаның ластануы экожүйелердің тұрақтылығына әсер етеді. Климаттың өзгеруі, шөлейттену, топырақ құнарлылығының төмендеуі және биоалуантүрліліктің азаюы да өзекті мәселелерге айналды. Бұл құбылыстар табиғатқа ғана емес, адамның денсаулығына, экономикаға және әлеуметтік жағдайға да ықпал етеді.

Қазақстан үшін су ресурстарын сақтау, Арал өңірінің экологиялық жағдайы, өнеркәсіптік аймақтардағы ауа сапасы, жердің тозуы мен тұрмыстық қалдықтарды басқару мәселелері ерекше маңызға ие. Табиғи ресурстарды шектен тыс пайдалану қысқа мерзімде экономикалық пайда әкелуі мүмкін, алайда ұзақ мерзімде қоғамға үлкен шығын келтіреді. Сондықтан табиғатты пайдалану кезінде бүгінгі қажеттілікпен қатар келешек ұрпақтың мүддесі де ескерілуі керек.

Экологиялық дағдарыстың себептерінің бірі – адамның табиғат алдындағы жауапкершілігін жеткілікті сезінбеуі. Қазіргі экологиялық философия табиғатпен үйлесімді өмір сүруді ғылыми біліммен ғана емес, моральдық ұстанымдармен де байланыстырады. Табиғатқа қатысты шешімдер қабылдағанда оның ұзақ мерзімді салдарын бағалау, ғылыми деректерге сүйену және табиғи заңдылықтарды ескеру қажет. 2026 жылғы зерттеуде де

экологиялық дағдарысты еңсеру үшін табиғатпен үйлесім, дәстүрлі және ғылыми білімнің сабақтастығы, сондай-ақ адамзаттың моральдық жауапкершілігі маңызды екені көрсетіледі [3, 38–41 бб.].

Адам мен табиғат үйлесімін сақтауда экологиялық мәдениетті қалыптастырудың маңызы зор. Экологиялық мәдениет – адамның табиғат туралы білімі, оған деген құндылықтық көзқарасы және қоршаған ортаға зиян келтірмей әрекет ету дағдысы. Ол отбасында, білім беру ұйымдарында, қоғамдық ортада және бұқаралық ақпарат құралдары арқылы қалыптасады. Мектеп пен жоғары оқу орындарында экологиялық білім беру табиғи ресурстарды қорғаудың себептері мен жолдарын түсіндіруге, жауапты азаматтық ұстаным қалыптастыруға көмектеседі.

Күнделікті өмірде әр адам суды және электр энергиясын үнемдеу, қоқысты сұрыптау, бір рет қолданылатын заттарды азайту, ағаш отырғызу, қоғамдық орындарды таза ұстау сияқты әрекеттер арқылы табиғатты қорғауға үлес қоса алады. Сонымен бірге өндіріс орындары экологиялық талаптарды сақтап, қалдықтарды азайтуға және қауіпсіз технологияларды енгізуге міндетті. Мемлекет табиғи аумақтарды қорғау, экологиялық заңнаманы жетілдіру және халықтың экологиялық сауаттылығын арттыру бағытында жүйелі жұмыс жүргізуі қажет.

Тұрақты даму қағидасы осы міндеттерді біріктіреді. Оның мәні – экономикалық өсуді, әлеуметтік әл-ауқатты және қоршаған ортаны қорғауды өзара үйлестіру. Табиғи байлықтарды бүгінгі ұрпақтың қажетіне жарата отырып, олардың келешек ұрпаққа да жеткілікті болуын қамтамасыз ету – адамзаттың ортақ міндеті [3, 41–43 бб.].

Адам мәселесі, оның ішінде шығу тегі, мәні , табиғаттағы оның орны және қоғамдық өмірдегі оның рөлі мәселелері фундаменталдық философиялық такырыптардың бірі болып табылады. Философияның пайда болғанан қазіргі уақытқа дейін адам оның басты назарында болды, ал бүгінгі күндері адам әрекетінің әртурлі қырларын зерттеуді негізгі мақсат тұтатын өзге де ғылыми салалар пайда болды. [4, 145 бб.]

Қорыта айтқанда, адам мен табиғат үйлесімі – өркениетті қоғамның өмір сүруінің негізгі шарттарының бірі. Табиғат адамға тіршілік негізін береді, ал адам оның сақталуына жауапты. Қазақ халқының дәстүрлі дүниетанымындағы Жер-Ана ұғымы, туған жерді қастерлеу, су мен өсімдікті қорғауға бағытталған тыйымдар бүгінгі экологиялық мәдениет үшін маңызды рухани мұра болып табылады.

Қазіргі экологиялық мәселелерді шешу үшін ғылым мен технологияның жетістіктерін пайдалану жеткіліксіз; сонымен қатар адамның табиғатқа деген көзқарасы өзгеруі керек. Әрбір азамат табиғи ресурстарды ұқыпты пайдаланып, қоршаған ортаға жауапкершілікпен қарауды күнделікті дағдыға айналдырғаны жөн. Табиғатпен үйлесімді өмір сүру – тек бүгінгі күннің талабы емес, болашақ ұрпақ алдындағы адамгершілік парыз. Табиғатты қорғау арқылы адам өз өмірін, денсаулығын және келешегін қорғайды.

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Art History

Kazakhstani designers on global runways

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Андатпа: Қазіргі қазақ сәні – көшпенділердің тарихи мұрасы, заманауи жаһандық көше стилі және минимализмнің үйлесімді тоғысуы. Ол жай ғана киім деңгейінен көтеріліп, ұлттық және мәдени бірегейлікті білдіретін тілге айналды. Төменде таныстырылымға арналған құрылымдық жоспар мен негізгі сипаттамалар тізімі берілген. Практикалық мәні: Киімдер атқа мінуге ыңғайлы болуы және шұғыл континенттік климаттан (дала желдері, қатты ыстық пен аяз тән) қорғауы үшін жасалған. Материалдар: Табиғи былғары, киіз, тері, жүн мата, барқыт және жібек. Әлеуметтік мәртебе маңызды рөл атқарған: Киім адамның жасын, тегін және қоғамдағы орнын дәл көрсететін болған (мысалы, бай өрнектелген қалыңдық бас киімі – сәукеле немесе ерлердің дәстүрлі сырт киімі – шапан).

Түйін сөздер: Дизайн, материалдар, бренд, инновациялық материалдар.

Аннотация: Казахстанская мода сегодня — это яркий синтез кочевого исторического наследия и современного глобального стритстайла и минимализма. Она превратилась из просто одежды в язык национальной и культурной идентичности. Ниже представлен готовый структурированный план и ключевые характеристики для презентации. Утилитарность: Одежда создавалась для удобства верховой езды и защиты от резко континентального климата (степные ветры, жара и морозы). Материалы: Натуральная кожа, войлок, мех, сукно, бархат и шелк. Знаковую роль играл статус: Костюм точно отражал возраст, род и социальное положение человека (например, богато украшенный свадебный головной убор — саукеле или мужской чапан).

Ключевые слова: Дизайн, материалы, бренд, инновационные материалы.

Abstract: Contemporary Kazakh fashion is a vibrant synthesis of nomadic historical heritage, modern global street style, and minimalism. It has evolved from mere clothing into a language of national and cultural identity. Below is a structured outline and a list of key characteristics for a presentation. Utilitarianism: Garments were designed for comfort while horseback riding and for protection against a sharply continental climate (characterized by steppe winds, intense heat, and freezing cold). Materials: Natural leather, felt, fur, wool cloth, velvet, and silk. Status played a significant role: Attire precisely indicated an individual's age, lineage, and social standing (for example, the richly decorated bridal headdress known as a «saukele», or the traditional men's robe, the «chapan»).

Keywords: Design, materials, brand, innovative materials.

Kazakhstani designers are actively entering the international stage, presenting their collections at fashion weeks in Paris, Milan, New York, and Seoul.

Contemporary Kazakhstani fashion represents a unique synthesis of a nomadic cultural code, traditional craftsmanship, and current global trends—such as minimalism, street style, and sustainability.

Key Trends

The collections of Kazakhstani designers blend ethnic motifs—such as traditional ornaments, felt, handcrafted elements, and stylized features of national dress—with a minimalist urban or avant-garde aesthetic. This fusion has sparked keen interest among international critics and fashion buyers.

Defining Characteristics of Contemporary Kazakhstani Fashion

• Integration of the national identity: Designers actively incorporate traditional Kazakh ornaments, recognizable silhouettes, and motifs into both everyday and high-end apparel, moving beyond their traditional use in stage costumes or festive attire.

Reimagining traditional attire: Elements of historical costume—such as the «chapan» (robe), «kamzol» (vest/jacket), stylized waistcoats, or wrap-style cuts that fasten on the left—are being adapted to the rhythm of urban life.

A balance between minimalism and ethnic influence: Clean lines, simple contemporary silhouettes, and a neutral color palette are often complemented by striking hand-embroidery, leather, felt, or unique, original prints.

Functionality and ergonomics: The influence of a nomadic past is reflected in a focus on practicality—garments are designed to be comfortable, loose-fitting, and well-suited to sharp climatic shifts.

Sustainability and a zero-waste approach: A traditional, conscientious attitude toward materials—where patterns are crafted to minimize fabric scraps—is central to the philosophy of local brands.

Growing global recognition: Kazakhstani brands are making an increasingly confident mark on the international stage, blending a profound sense of national identity with a sophisticated aesthetic.

Notable examples of participation on the global stage:

• Aida KaumeNOVA — one of Kazakhstan's most renowned fashion houses (founded in 2006), whose collections consistently blend national character with contemporary trends on international platforms, including Milan Fashion Week.

• NUR-SHAH — a brand that has showcased its creations at the prestigious Paris Haute Couture Week.

• Atelier Arunaz — a participant in fashion shows held as part of Paris Fashion Air.

• Malli, Kamalini, and ShakerBaY — brands that have represented Kazakhstani fashion on international runways in Milan.

• Raushan Anuarbekova, Sabina Volskaya, and Timur Tursunkulov — designers who presented their work in New York as part of the Unique Fashion Show project.

Aya Bapani — a designer who received a gold award for original design in Milan.

Ainur Turisbek — a well-known designer who has presented her collections on international runways (including Ukrainian Fashion Week, among others).

Designers on the runway in Seoul — the Dongdaemun Design Plaza in South Korea hosted fashion shows by Kazakhstani brands, accompanied by both traditional and contemporary music.

Kazakhstani Designers Present Their Collections in New York

New York, September 13, 2026 — As part of the international "Unique Fashion Show" project, collections by three Kazakhstani designers—Raushan Anuarbekova, Sabina Volskaya, and Timur Tursunkulov—were showcased in New York.

The runway featured a diverse range of styles from the Kazakhstani fashion scene, including garments with traditional national motifs, contemporary womenswear, and elegant classic pieces.

Each collection showcased a distinct style and unique creative vision, highlighting the richness of Kazakhstan's cultural heritage blended with modern trends.

The participation of Kazakhstani designers and models in the Unique Fashion Show served as a significant milestone, introducing an international audience to the national aesthetics, creative potential, and distinct identity of Kazakh fashion.

On September 13, the event showcased three distinct styles: traditional attire incorporating authentic cultural elements, contemporary womenswear, and elegant classic fashion. Each designer employed a unique approach to tailoring while preserving key aspects of their cultural heritage.

Experts note that a modern approach to design generates sustained interest among international buyers even before a brand enters the market directly.

Kazakhstani fashion is no longer just a local phenomenon. Increasingly, the names of homegrown designers are appearing on Parisian runways, in the display windows of American department stores, and on the pages of international publications. We take a look at which of our compatriots have already conquered the global industry—and what sets their work apart from the typical offerings of mass-market fashion.

Malli

Manshuk Kuanysheva, known by the brand name Malli, became the first Kazakhstani designer to have a collection featured at the iconic American department store Saks Fifth Avenue. This marked a major breakthrough for the local industry, as securing a spot with such a retailer is an immense challenge—even for European brands.

The designer draws inspiration from the glamour of Old Hollywood, blending it with the aesthetic of Kazakhstani women—an approach that feels both traditional and contemporary. Kuanysheva received her education at an institute for fashion, design, and merchandising in Italy, a background clearly reflected in the quality of her tailoring and the presentation of her collections.

NUR-SHAH at Paris Haute Couture

The Kazakhstani brand NUR-SHAH presented a collection titled "Luned'Or" during Paris Haute Couture Fashion Week. The name translates to "Golden Moon" and alludes to a folk legend about Princess Altyn Ay, the daughter of the Creator of the Heavens.

A key element of the collection is a bespoke print, developed from traditional Kazakh ornaments. This approach demonstrates that Kazakh culture can speak the language of high fashion without losing its own distinct identity.

Arunaz Atelier and Participation in Paris Fashion Air

Designer Nazym Karpikova showcased her atelier, Arunaz, at the Paris Fashion Air event. The collection features an all-black palette—a striking contrast to the vibrant ethnic motifs typically associated with Kazakhstani brands.

This minimalist approach demonstrates that Kazakhstani designers are equally adept at working with both traditional national ornaments and the clean, understated silhouettes that resonate with the European market.

Aya Bapanova's Felt Fashion

Designer Aya—a member of the renowned Bapanov family of felt artisans—deserves special attention. Her handmade dresses are highly acclaimed and draw inspiration from the traditional attire of women from the Great Steppe.

A key strength of Kazakhstani designers is their willingness to experiment with their national cultural code. Traditional ornaments, felt, Saka-era motifs, and nomadic aesthetics are transformed into modern silhouettes that resonate with the global market.

At the same time, the younger generation does not rely on a single formula. Some find inspiration in futurism and dark aesthetics, others embrace minimalism, while some develop capsule collections in collaboration with international partners.

KAZAKHSTANI DESIGNERS PRESENTED THEIR NEW COLLECTIONS AT MILAN FASHION WEEK

As part of Milan Fashion Week SS27, a series of runway shows took place at the Leonardo da Vinci Museum of Science and Technology in Milan, bringing together designers from Central Asia and Europe, alongside representatives of the international "modest fashion" movement.

Kazakhstani designers opened the fashion week. The runway featured Kazakhstani brands Aida Kaumenova, Kamalini, and ShakerBaY, as well as REVE (from Saint Petersburg), SA_Marail, Puti Tenk, and Aynaeva. The event served as a platform for cultural dialogue, introducing an international fashion audience to a contemporary interpretation of Central Asian traditions.

A special place in the program was held by the collection showcases from designers representing Kazakhstan Fashion Week. Aida Kaumenova presented a contemporary reinterpretation of traditional Kazakh forms and headwear. The show opened with a performance by Kazakhstani cellist and conductor Eldar Sapaar, who played a piece by composer Kuat Shildebayev. This musical accompaniment served as a symbolic link between contemporary art and the cultural heritage of Central Asia.

ShakerBaY presented a contemporary take on the layered style of traditional nomadic attire. Mira Shakerbay spoke about her collection and her approach to working with national motifs: "I drew inspiration from the inner strength of women. For me, it’s not just about incorporating national elements and ornaments; it’s about reimagining them through modern design, a light-handed approach, distinct silhouettes, and natural fabrics. This is how garments are created—pieces that speak to our identity in the language of global fashion."

The collections blended elements of Kazakhstan’s cultural heritage—such as ornaments, embroidery, traditional techniques, materials, and the aesthetics of nomadic culture—with modern silhouettes and international trends.

"We are proud that our country’s top designers are represented in Milan—the very heart of international fashion," noted Sayat Dosybayev, General Director of Kazakhstan Fashion Week.

"The Milanese press has noted that brands from Kazakhstan are not only distinctive and imbued with a national DNA, but they also compellingly reflect seasonal trends and fit seamlessly into the context of one of Europe’s most renowned fashion weeks. They are being tipped for a bright future at Milan Fashion Week," said Nadezhda Kozhevnikova, founder of the Paris-based B2B showroom New Couture.

The participation of Kazakhstani brands in Milan Fashion Week demonstrates the development of the national fashion industry and its commitment to international dialogue. Today, Kazakhstan is shaping its own professional fashion landscape through fashion weeks, competitions, and specialized platforms in Astana and Almaty.

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